1983 DOE AUTHORIZATION
(Transportation Programs)

HEARINGS

BEFORE THE

SUBCOMMITTEE ON TRANSPORTATION, AVIATION, AND MATERIALS

OF THE

COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

NINETY-SEVENTH CONGRESS

SECOND SESSION

MARCH 2, 3, 1982

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1983 DOE AUTHORIZATION

TUESDAY, MARCH 2, 1982

House of Representatives, Committee on Science and Technology, Subcommittee on Transportation, Aviation, and Materials,

Washington, D.C.

The subcommittee met, pursuant to notice, at 10:01 a.m., in room 2318, Rayburn House Office Building, Hon. Dan Glickman (chairman of the subcommittee) presiding.

Present: Representatives Glickman, Harkin, Shamansky, and Dunn.

Mr. Glickman. The subcommittee will be in order.

Today the subcommittee will begin 2 days of hearings on the Department of Energy programs in transportation technology.

As most of you probably know, these programs were created largely by two pieces of legislation that began in this committee, and so we are particularly interested in monitoring their progress.

Unfortunately, the administration views them as welfare for the automobile industry. I do not believe that that is an accurate description, even though some of our automakers could probably use a little welfare right now. These research programs are really a modest investment in the future.

In my judgment, we seem to understand this important principle when it comes to the aircraft industry. The Government has invested heavily in new aeronautical technology over many years, and the results are plainly evident in our balance-of-trade figures.

Certainly the Japanese understand the need for Government support of basic automotive research and development, and their trade figures show the result.

So why is the administration proposing to truncate our own minimal efforts—and truncate them just when the first results are coming in? In case anybody does not know what the word "truncate" means, it means to zero out totally. If the reason is to save money in fiscal year 1983, that can certainly be done. But I believe that the Government has a responsibility to look beyond the immediate future. We must assure that our citizens will be secure both militarily and economically in the years to come, and programs such as these are an important part.

During these hearings, we will hear from many of the participants in DOE's program. Today we will have the industry side; tomorrow, the Government.

Before I begin, I would like to read a letter from another group who could not testify this morning. The letter is from Mr. Sheldon

Friedman, research director, and Mr. Dick Warden, legislative director, of the United Auto Workers.

The entire letter will appear in the record, but I will read the important, relevant provisions as they relate to our subcommittee's jurisdiction:

> As we testified before your subcommittee last July, there is a pressing need for government-sponsored basic and applied automotive research. During the current auto crisis, the U.S. carmakers are being forced to concentrate on massive retooling at a time of heavy losses. Under such conditions, it is doubtful whether adequate emphasis can be given to basic propulsion research.
>
> The United States cannot afford a slowdown in the overall effort to stay competitive in engine technology. The transportation program that now faces complete elimination under the proposed 1983 DOE budget has focused on proving the concept of the Stirling engine and the gas turbine. The first results are only now coming in, and we understand they are most encouraging. This is hardly the time to kill the program.
>
> An article in the December 11, 1981, NIKKAN Industrial Journal, a Japanese journal, reveals that the Japanese have quietly been pushing forward with their own Stirling engine program, better funded than our own. In fact, the article states that one reason for the Ministry of Trade and Industry's haste in encouraging Stirling and other power plant work is Japan's fear of getting too far behind DOE's 1984 load proving test schedule. If this program is scrapped, the Japanese automakers gain yet another advantage by default.
>
> We urge continued funding of vehicle propulsion research in DOE's transportation program and commend you for holding these hearings to make the Congress and the public aware of the grave harm that would result from shortchanging the nation's automotive technology research efforts.

[The letter mentioned above follows:]

(short)

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UAW

INTERNATIONAL UNION, UNITED AUTOMOBILE, AEROSPACE & AGRICULTURAL IMPLEMENT WORKERS OF AMERICA-UAW

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February 25, 1982

Congressman Dan Glickman, Chairman
Subcommittee on Transportation, Aviation and Materials
House Committee on Science and Technology
2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. Chairman:

The UAW is submitting this letter for the record of your March 2-3, 1982 oversight hearings on the transportation program within the Department of Energy.

As we testified before your Subcommittee last July, there is a pressing need for government-sponsored basic and applied automotive research. During the current auto crisis, the U.S. carmakers are being forced to concentrate on massive retooling at a time of heavy losses; under such conditions, it is doubtful whether adequate emphasis can be given to basic propulsion research.

The U.S. cannot afford a slowdown in the overall effort to stay competitive in engine technology. The transportation program that now faces complete elimination under the proposed FY 1983 DOE budget has focused on proving the concept of the Stirling engine and the gas turbine. The first results are only now coming in, and we understand they are most encouraging. This is hardly the time to kill the program!

As you are no doubt aware, the UAW strongly supports enactment of domestic content legislation (H.R. 5133). Among other things, this legislation would require Japanese automakers to invest in the U.S., where they enjoy a $15-billion annual new vehicle market. Our support for this legislation reflects a growing concern that unless automotive investment in the U.S. is mandated, more and more production, engineering, design, and research activity will go down the drain, at further cost to our nation's depleted industrial base.

An article in the December 11, 1981 "NIKKAN Industrial Journal" reveals that the Japanese have quietly been pushing forward with their own Stirling engine program, better funded than our own. In fact, the article states that one reason for the Ministry of Trade and Industry's haste in encouraging Stirling and other power plant work is Japan's fear of getting too far behind DOE's 1984 load proving test schedule. If this DOE program is scrapped, the Japanese automakers gain yet another advantage by default.

We urge continued funding of vehicle propulsion research in DOE's transportation program, and commend you for holding these hearings to make the Congress and the public aware of the grave harm that would result from shortchanging the nation's automotive technology research efforts.

Sincerely yours,

Sheldon Friedman
Dick

Sheldon Friedman
Research Director

Dick Warden
Legislative Director

Mr. **GLICKMAN**. Before we begin with the testimony, I would like to call upon the acting ranking minority member, Mr. Dunn, of the relevant State of Michigan, to make any remarks that he would like to make.

Mr. **DUNN**. I do not have any remarks at this time.

Mr. **GLICKMAN**. Let's go ahead with our testimony. The first witness is, the Garrett and Ford consortium on the gas turbine. We have Mr. John Boppart, vice president of engineering of Garrett, and Mr. Richard Ronzi, director of the power train research division of the Ford Motor Co.

So you may proceed as you deem appropriate. I might tell you that all of your statements will appear in their entirety in the record. So if you want to summarize, that is fine with me. So proceed as you wish.

STATEMENTS OF JOHN BOPPART, VICE PRESIDENT, ENGINEERING, GARRETT TURBINE ENGINE CO., AND RICHARD RONZI, DIRECTOR, POWER TRAIN RESEARCH, FORD MOTOR CO.

Mr. **BOPPART**. Thank you. We will be using slides to illustrate our talk this morning.

As you have indicated, I am John Boppart and this is Dick Ronzi.

Garrett is a member of the Signal Cos. Signal is well known as a supplier to the needs of the transportation industry because of its activity by Garrett in gas turbines and turbochargers and by Mack Truck in large vehicles [fig. 1].

Garrett and the Ford Motor Co. are working together to develop high-risk, long-range technology needed for an advanced gas turbine for automotive and other powerplants of the future.

Garrett is the prime contractor, with major support from Ford. We are currently under contract to the Department of Energy and NASA. Both companies are cost sharing in this program.

Garrett is a world leader in small gas turbine and turbocharger technology and products for a variety of aerospace, transportation, and industrial applications. We bring to this program our expertise in advanced gas turbine development, including ceramics, while Ford brings automotive expertise as well as its extensive ceramics capability.

In addition to Garrett and Ford, we have other major subcontractors, as indicated, on this program, such as Carborundum, Corning Glass, and the AiResearch Casting Co., another division of Garrett. All of these companies are conducting research and development of ceramic parts for the AGT program [fig. 2].

Other subcontractors and vendors are located around the country as shown [fig. 3].

The automotive advanced gas turbine program was established under Public Law 95-238, title III, "Automotive Propulsion Research and Development." Although the program was intially planned as a commercialization program to assist industry in developing fuel-efficient powerplants for future automobiles, the present engineering development phase is truly a high-risk, long-range technology program, consistent with the current administration's guidelines for Government support. This is especially true as a result of some program reorientation that has occurred in the last year [fig. 4].

You will note from the accompanying charts that this nation continues to be very reliant on imported petroleum [fig. 5].

Further, transportation is the major consumer of petroleum. The automobile, of course, consumes most of this petroleum. Significant progress has been made in reducing fuel consumption, but consumption of petroleum must continue to be reduced. Petroleum supplies are being depleted, foreign suppliers are not dependable, and the continued imbalance of trade associated with costly foreign oil depresses our economy [fig. 6].

We all know that foreign automobile companies have secured a large share of the United States and world market. We also find that foreign governments are heavily supporting research of advanced technology engines. Not only is our auto industry facing immediate market and financial problems, but we face potentially more difficult challenges in the future as well, unless our Government continues to support technology for future powerplants better than those of our foreign competitors. The AGT is just such a program.

The AGT program started on the first of October 1979 and was scheduled for 5 years and 8 months. The program objectives are briefly outlined here. The 42.8 miles per gallon was to be accomplished over the combined Federal metro-highway driving cycle, which is mostly city, in a 3,000-pound car, powered by the AGT101 gas turbine. Note that a variety of fuels are to be used with the AGT [fig. 7].

The AGT program schedule reflects the milestones originally stipulated in the contract. Primary among these are operation of an engine on a dynamometer in 1984 and, finally, a demonstration in a vehicle in 1985 [fig. 8].

However, as a result of a 20-percent budget cut midway through fiscal year 1981 which resulted in a 40-percent reduction for the rest of the year, there has been a significant change to the program. Our team, with NASA and DOE concurrence, chose to defer the automotive and transmission/gearbox tasks and concentrate on the long-range, high-risk gas turbine technology so vitally needed. We fashioned such a program consistent with Ford's schedule needs.

I would like to emphasize our belief that this Government/industry team should be allowed to finish the program. It is very important to the program that DOE and NASA be allowed to continue to manage the Garrett/Ford team. Loss of continuity of management, contractual, and technical direction would compromise the successful accomplishment of the program goals.

The Garrett/Ford advanced gas turbine, designated the AGT101, was to be a complete power train composed of a single shaft gas turbine coupled to a speed reduction gearbox and a production four-speed automatic transmission [fig. 9].

The AGT power section, wherein lies the technology now under development, is rated at 100 horsepower, with speeds to 100,000 r.p.m. and temperatures as high as 2,500° F. With some assistance, we will ask you to note the simple rotating assembly comprising a single aluminum compressor wheel, a single ceramic turbine wheel supported by an air-lubricated bearing. This requires no oil lubication in the engine. An oil-lubricated bearing is located in the gearbox where transmission oil is available [fig. 10].

A ceramic rotating regenerator is utilized to recover waste heat that would otherwise be lost. This increases the engine's efficiency, thus enhancing fuel economy. Note that the ceramic parts are symmetrical in shape to allow ease of fabrication, reduction of stresses, and eventual low cost. Thus, a major effort is directed at developing ceramic materials beyond presently available technology.

At this time, our ceramic suppliers have provided the initial components shown in the figure to be tested in our rigs prior to installation in the engine [fig. 11].

It should be emphasized that ceramics can replace strategic materials currently used in high temperature engines that are expensive and are provided, in many cases, by foreign countries whose supplies are not always reliable. The strategic materials are being depleted, like petroleum, and are not replaceable [fig. 12].

President Reagan's crusade to rebuild America's military power is focusing new attention on this country's reliance on other nations for these strategic materials. Realization of this potentially dangerous dependence on foreign sources is prompting the White House to rebuild the U.S. strategic stockpile, intensify domestic mining, and open offshore waters for exploration of vital minerals.

Without metal ores imported from the Soviet Union or unstable countries such as Zaire and Zimbabwe, it would be virtually impossible to manufacture the sophisticated weaponry needed for modern-day warfare.

Note the chart [fig. 13] of one of our Nation's latest jet engines and the amount of strategic materials imported from foreign countries. I know you cannot read those numbers, but they are like 5,000 pounds of titanium and 5,000 pounds of nickel and almost 1,000 pounds of columbium and cobalt.

Ceramics could replace a majority of these metals. Last March, President Reagan proposed spending $100 million to buy materials for the Nation's strategic stockpiles.

Ceramic elements are readily available within the United States and other friendly nations [fig. 14]. Silicon and nitrogen are elemental constituents of ceramics and, as you can see, there is an essentially inexhaustible supply available at low cost. Even if the strategic materials were continued to be used in the engine, there is not an adequate worldwide supply for automotive production quantities.

As previously mentioned, the AGT 101 will operate at internal temperatures of 2,500° F. That is the far right of that chart [fig. 15]. The chart shows that ceramics can withstand these temperatures without loss of strength. The strength of the strategic materials shown, which is about the best available now in use in gas turbines, drops off dramatically with temperature and must have substantial cooling to be usable at high temperature, resulting in poorer efficiency and lower fuel economy.

This figure graphically compares the relative cost of strategic materials to ceramics [fig. 16].

By now you see that ceramics are vital to the program and to our country's future. The AGT program utilizes nearly all of our country's ceramic expertise, as shown here [fig. 17].

In addition, the DOE/NASA AGT and related programs are the only significant source of Government funding for this critical technology development [fig. 18].

At this point, I would like to tell you some of the accomplishments we have achieved in the AGT 101 program in spite of the reduced funding.

Our first engine, which incorporates mostly metal parts, is now in test at our Phoenix facility. We have been operating this engine [fig. 19] since late last summer to develop its capabilities such that the ceramic parts can be introduced as soon as they pass our rig tests. We intend to introduce more ceramic parts later this year and to have all the ceramics integrated next year.

Good progress has been made by our ceramic suppliers in developing the ceramic parts. Japanese firms are providing, at no cost, some ceramic parts to the AGT program. This follows closely the Japanese strategy to corner the ceramic substrate market in this country. For this reason, we have opted to incur the higher expense of developing domestic sources in order to insure that this Nation will have qualified ceramic suppliers in the future. The basic intent of this program is to utilize the taxpayers' money for the development of American technology.

An especially tough problem involves the ceramic turbine rotor [fig. 20]. The rotor is essential for low cost, high production use in automobiles. Both Ford and AiResearch Casting Co. have successfully passed the initial requirements of spinning bladeless rotors, the part on the right, and are now building bladed rotors. This is the first time that ceramic rotors of this thickness have exceeded stress levels we expect in our engine.

It should be emphasized that ceramics cannot be developed independent of the environment in which they will be operating. It is an iterative process, and to do ceramic technology work at universities or ceramic companies only, without integrating the ceramics into the engine environment, will not be successful in a reasonable period of time.

In addition to the ceramics and engine testing, we have also successfully tested a number of our component rigs, including the compressor and turbine shown here [fig. 21].

The combustor and the rotary regenerator [fig. 22].

And the rotor dynamics, to name the major ones [fig. 23].

We successfuly accomplished the first milestone in the program on time, which was design reviews of the metal and ceramic engines.

As mentioned earlier, due to budget constraints, we have deferred automotive, transmission, and gearbox tasks. This does not compromise the high-risk technology development of the program. It does impact the future preproduction costs which will be borne entirely by industry. This is consistent with the current administration policy.

The AGT 101 will provide excellent fuel economy for future automotive and other application powerplants. Ford has recently performed a study wherein alternative powerplants were evaluated for automobiles of the 1990-plus time period [fig. 24]. The study, conducted independent of the AGT program, demonstrates that the ceramic gas turbine offers the best potential efficiency of any candidate powerplant.

When combined with improved transmissions, the ceramic gas turbine retains this advantage [fig. 25].

What does this mean in the way of fuel economy? This chart compares the AGT 101 vehicle to average 1981 diesel and gas vehicles over the metro-highway driving cycle [fig. 26]. As previously stated, the program goal was to demonstrate that the AGT 3,000-pound vehicle, a Ford Fairmont size, would achieve 42.8 miles per gallon.

The shaded band reflects potential improvements that are envisioned in the next few years in transmission efficiencies and vehicle characteristics. These improvements are displayed over a range of automobile weights and, of course, offer greater economies with lower vehicle weights.

This study has been confirmed by a NASA study performed in 1981 [fig. 27].

When the AGT vehicle is operated at a fixed speed, the fuel economy with current transmissions could be 70 miles per gallon at 30 miles an hour and 57 miles per gallon at 50 miles an hour using diesel fuel. Even with these outstanding fuel economies, the car will have comparable driveability and acceleration to today's vehicles of similar weight and will also meet emission, noise, and safety requirements.

Another extremely important feature of this engine is its capability to operate on a variety of fuels without loss of efficiency [fig. 28]. Traditional fuels, such as gasoline and diesel, will, of course, be usable. Alcohol derived from coal or biomass can also be used. In addition, methane, future coal-derived fuels or synethic fuels are to be included in the AGT's combustion capability.

The AGT technology is applicable to other powerplants of the future. The AGT 101 is an ideal candidate for dispersed solar thermal generator sets that could reduce the country's demand for fossil fuel [fig. 29].

Garrett is currently conducting a program for DOE, NASA, and the Jet Propulsion Laboratory in which one of the AGT 101 engines is being slightly modified to operate on either solar energy, fossil fuel, or both. It is planned that this engine will be tested this summer at Jet Propulsion Laboratory's Edwards Air Force Base test facility on a point-focusing solar concentrator such as shown here.

Further, multifueled generator sets for potential military use are being considered [fig. 30]. The advantage of light-weight and all-weather gas turbines for military generator sets has long been recognized. Today, they are not available to our Army because of the high fuel consumption of today's gas turbine engines. The AGT 101 solves this problem, providing all these advantages to our future military needs.

Other attractive applications for the AGT 101 include the tractor or construction equipment markets. In these cases, multifuel capability is of strong interest.

Under consideration are various engine cycles utilizing the technology for general aviation propulsion and aircraft auxiliary power units [fig. 31]. The low fuel consumption of such an engine would far surpass existing engine capability.

The aforementioned applications offer a potential market for thousands of fuel-efficient AGT-type powerplants. The Government needs to assist industry in bringing the technology to the level where industry can afford to carry it on to production.

As discussed earlier, when the funding reductions occurred in 1981, Garrett and Ford recommended the reorientation of the program to concentrate on high-risk, long-range technology that industry could not afford to finance. The recommended program we offered to this subcommittee verbally during our testimony on March 12, 1981, and subsequently by letter is repeated here [fig. 32].

Four years of concentrated ceramic and component technology effort is recommended to bring the AGT 101 to the point where the performance, power and emissions would be demonstrated in an engine dynamometer. In addition, the ceramic parts will have been tested in the engine and deemed economically viable for mass production by the auto industry.

If this could be demonstrated, Ford would then be in a position to carry the program forward in a 6- to 8-year production engineering timeframe so that production could be initiated in the early 1990's.

The timing for completion of these milestones is extremely important, as a stretchout will only delay implementation of this technology into automobiles and the other applications.

Last year, when we recommended the program, it was estimated that the cost per year would be in the $8 to $10 million range. We feel that these estimates are still valid. However, the funding for fiscal year 1982 has also been curtailed. We are presently being funded on a monthly basis at a rate which will result in only the $6 to $7 million level. This funding is inadequate to meet the redefined milestones in fiscal year 1985 and should be corrected promptly in order to avoid delays in the program.

Foreign competition is keen. Daimler-Benz, supported by the German Federal Ministry, recently announced that they had successfully tested a ceramic rotor for over 140 hours in their ceramic automotive gas turbine [fig. 33].

The Japanese are actively developing ceramics and fuel-efficient power plants of the future [fig. 34].

They recently announced that they have ceramic piston engines that are soon to be introduced into production [fig. 35].

We know that they are active in gas turbine development, and we are concerned that they may introduce a ceramic gas turbine vehicle in advance of the United States. This would further erode our automotive market share and the balance of trade [fig. 36].

Let us again ask, why should the Government support the AGT program? We believe the current program is an advanced, long-range, high-risk powerplant technology program consistent with the administration's guidelines [fig. 37]. It will aid in reducing our country's energy consumption and dependence on foreign oil.

The program will reduce our dependence on expensive foreign strategic materials. And finally, the foreign government-subsidized competition is keen and must not be allowed to further degrade our industrial market share and balance of trade.

Why does the Garrett/Ford AGT 101 program fulfill these needs [fig. 38]? The AGT 101 will be a test bed for technology advancement in the areas of ceramics, multifuel capability, heat recovery, and other performance improvements. Ceramics offer many advantages for future powerplants such as low cost, available constituents within our country, improved engine efficiency, and lighter weight vehicles, which in turn improve fuel economy.

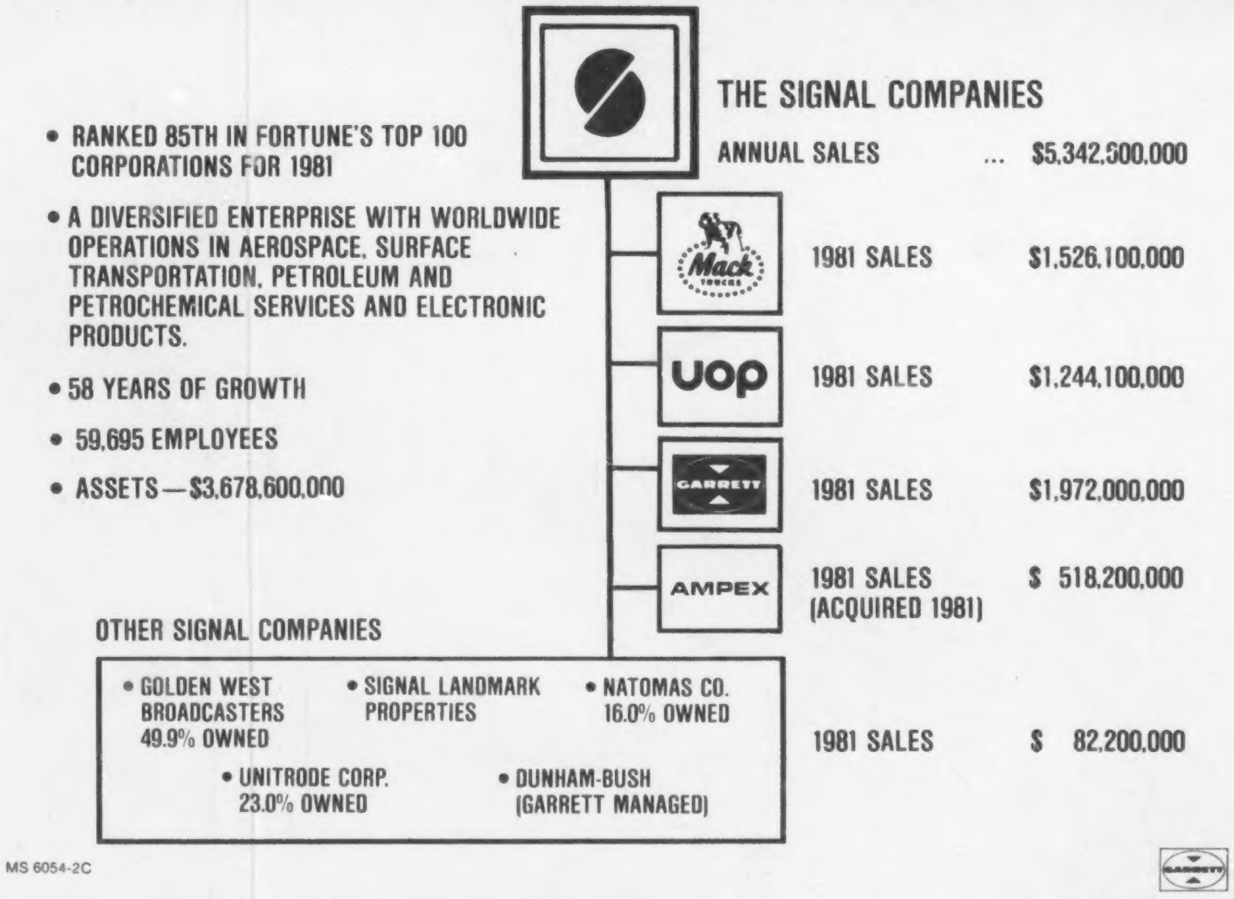
As reflected in Ford's recent study, the ceramic gas turbine is the best potential future automotive powerplant.

We recommend that the current DOE/NASA team be retained to manage this program to avoid delays due to loss of continuity in management, contractual, and technical direction.

We further recommend that current funding be restored to a level which will allow the expeditious development of this very important high-risk technology. This will allow industry to carry forward the program in a timely fashion.

Thank you for this opportunity to testify. Mr. Ronzi will now present a brief statement prepared by Ford. Then we will be pleased to answer questions you might have.

[Figs. 1–38 of Mr. Boppart's statement follow:]



THE SIGNAL COMPANIES

- RANKED 85TH IN FORTUNE'S TOP 100 CORPORATIONS FOR 1981
- A DIVERSIFIED ENTERPRISE WITH WORLDWIDE OPERATIONS IN AEROSPACE, SURFACE TRANSPORTATION, PETROLEUM AND PETROCHEMICAL SERVICES AND ELECTRONIC PRODUCTS.
- 58 YEARS OF GROWTH
- 59,695 EMPLOYEES
- ASSETS—$3,678,600,000

	ANNUAL SALES ...	$5,342,500,000
Mack Trucks	1981 SALES	$1,526,100,000
uop	1981 SALES	$1,244,100,000
GARRETT	1981 SALES	$1,972,000,000
AMPEX	1981 SALES (ACQUIRED 1981)	$ 518,200,000
OTHER SIGNAL COMPANIES	1981 SALES	$ 82,200,000

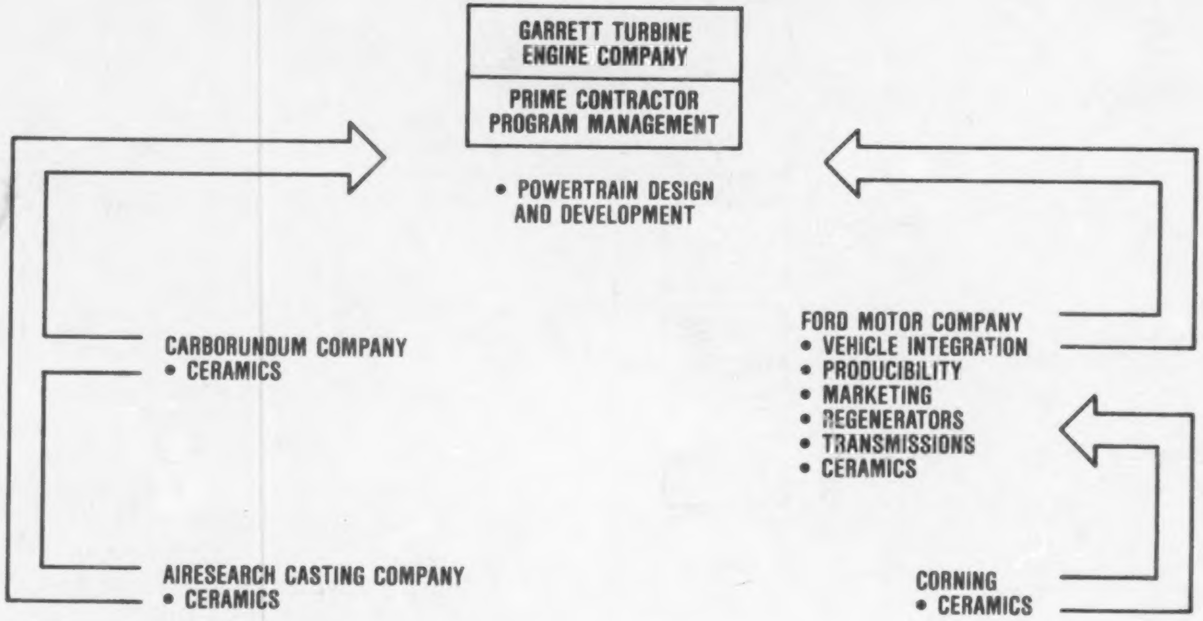
OTHER SIGNAL COMPANIES

- GOLDEN WEST BROADCASTERS 49.9% OWNED
- SIGNAL LANDMARK PROPERTIES
- NATOMAS CO. 16.0% OWNED
- UNITRODE CORP. 23.0% OWNED
- DUNHAM-BUSH (GARRETT MANAGED)

MS 6054-2C

Figure 1

GARRETT/FORD AGT101 PROGRAM TEAM



GARRETT TURBINE ENGINE COMPANY

PRIME CONTRACTOR PROGRAM MANAGEMENT

- POWERTRAIN DESIGN AND DEVELOPMENT

CARBORUNDUM COMPANY
- CERAMICS

AIRESEARCH CASTING COMPANY
- CERAMICS

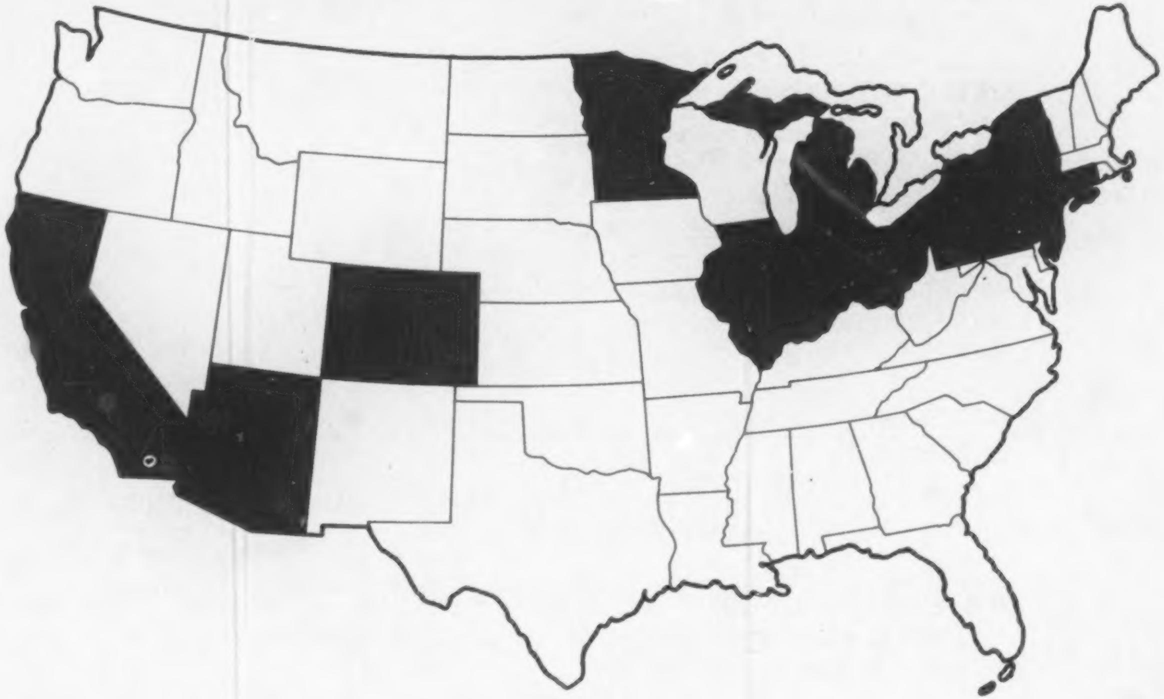
FORD MOTOR COMPANY
- VEHICLE INTEGRATION
- PRODUCIBILITY
- MARKETING
- REGENERATORS
- TRANSMISSIONS
- CERAMICS

CORNING
- CERAMICS

MS 6707-3

FIGURE 2

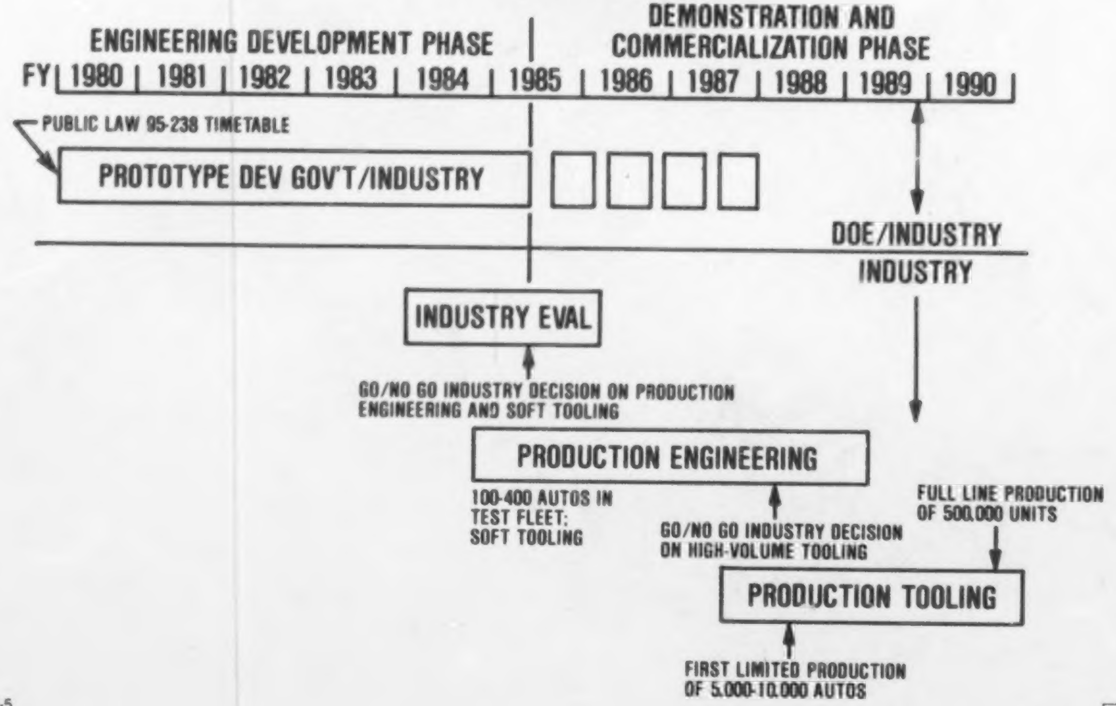
AGT101 SUB-CONTRACTORS AND SUPPLIERS



MS 6707-4

FIGURE 3

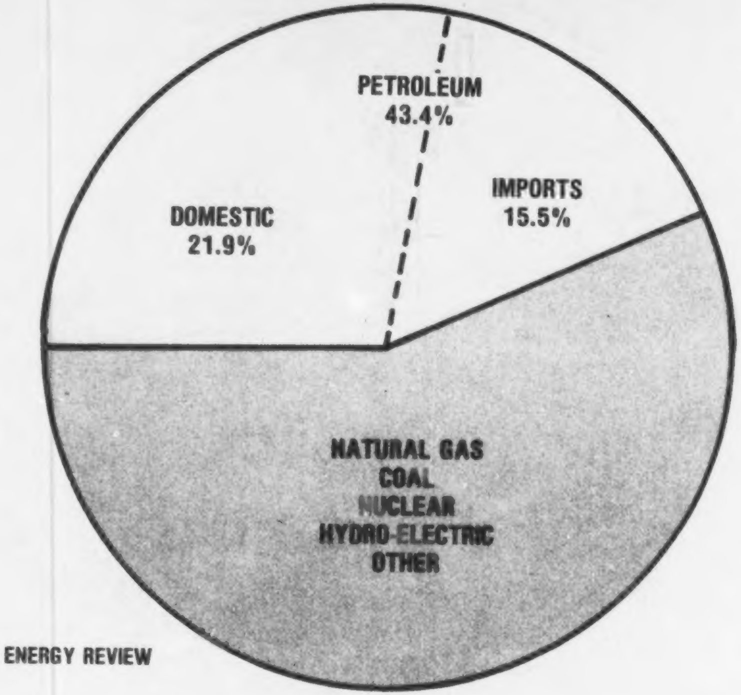
AUTOMOTIVE ADVANCED GAS TURBINE PROGRAM


ENGINEERING DEVELOPMENT PHASE
DEMONSTRATION AND COMMERCIALIZATION PHASE
FY
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
PUBLIC LAW 95-238 TIMETABLE
PROTOTYPE DEV GOV'T/INDUSTRY
DOE/INDUSTRY
INDUSTRY
INDUSTRY EVAL
GO/NO GO INDUSTRY DECISION ON PRODUCTION ENGINEERING AND SOFT TOOLING
PRODUCTION ENGINEERING
100-400 AUTOS IN TEST FLEET: SOFT TOOLING
GO/NO GO INDUSTRY DECISION ON HIGH-VOLUME TOOLING
FULL LINE PRODUCTION OF 500,000 UNITS
PRODUCTION TOOLING
FIRST LIMITED PRODUCTION OF 5,000-10,000 AUTOS

MS 6707-5

FIGURE 4

U.S. ENERGY CONSUMPTION
JAN-SEPT. 1981

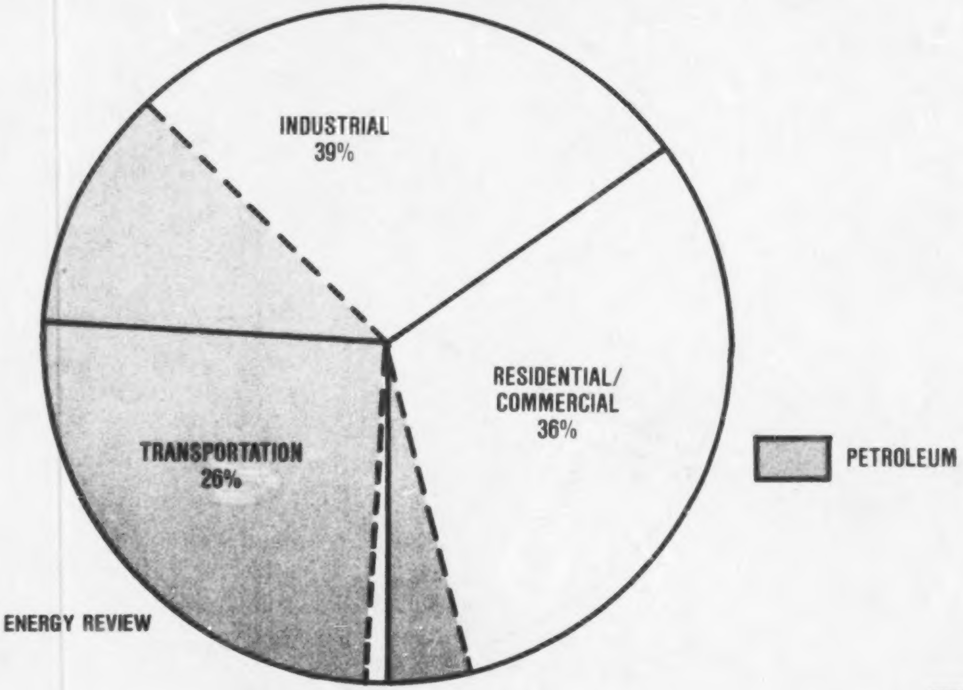


SOURCE: DOE MONTHLY ENERGY REVIEW
DEC. 1981

MS 6707-6

FIGURE 5

U.S. ENERGY CONSUMPTION
JAN-SEPT. 1981



SOURCE: DOE MONTHLY ENERGY REVIEW
DEC. 1981

MS 6707-7

Figure 6

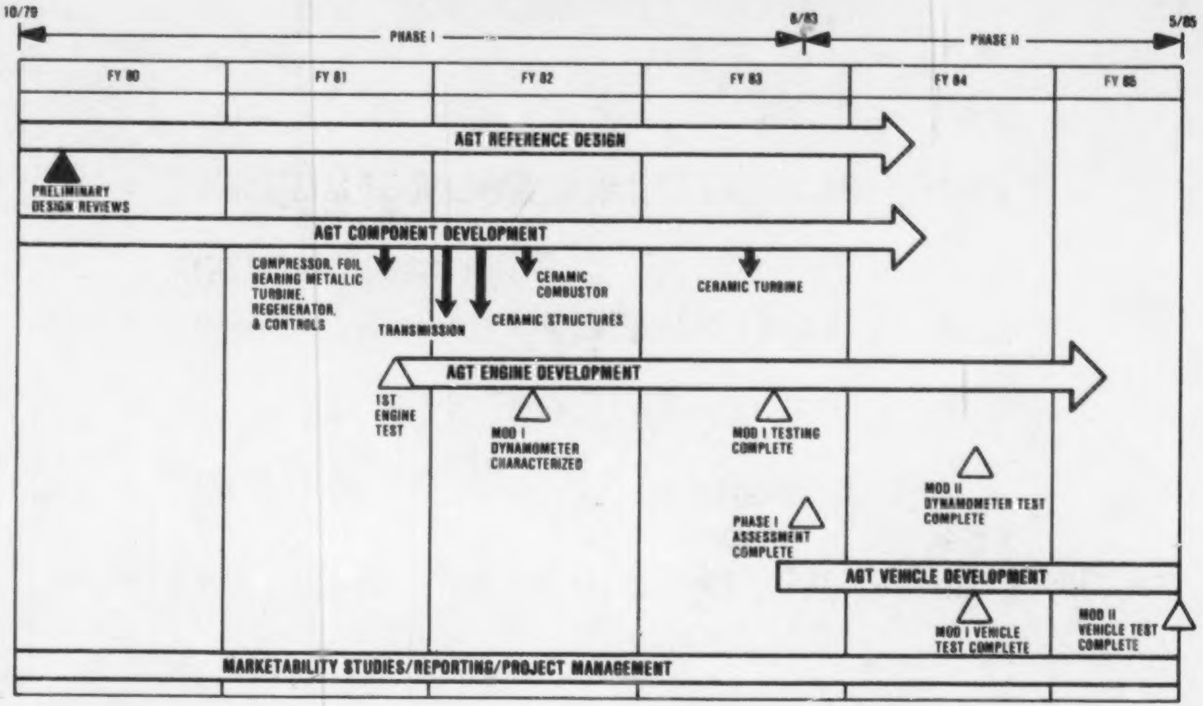
AGT PROGRAM OBJECTIVES

- 42.8 MPG M-H (DIESEL FUEL) IN 3000 POUND VEHICLE
- ABILITY TO USE VARIETY OF FUELS
- MEET EMISSIONS STANDARDS
- SAME DRIVEABILITY & PERFORMANCE AS SPARK IGNITION VEHICLE
- COMPETITIVE INITIAL COST & LIFE CYCLE COST

MS 6707-10

FIGURE 7

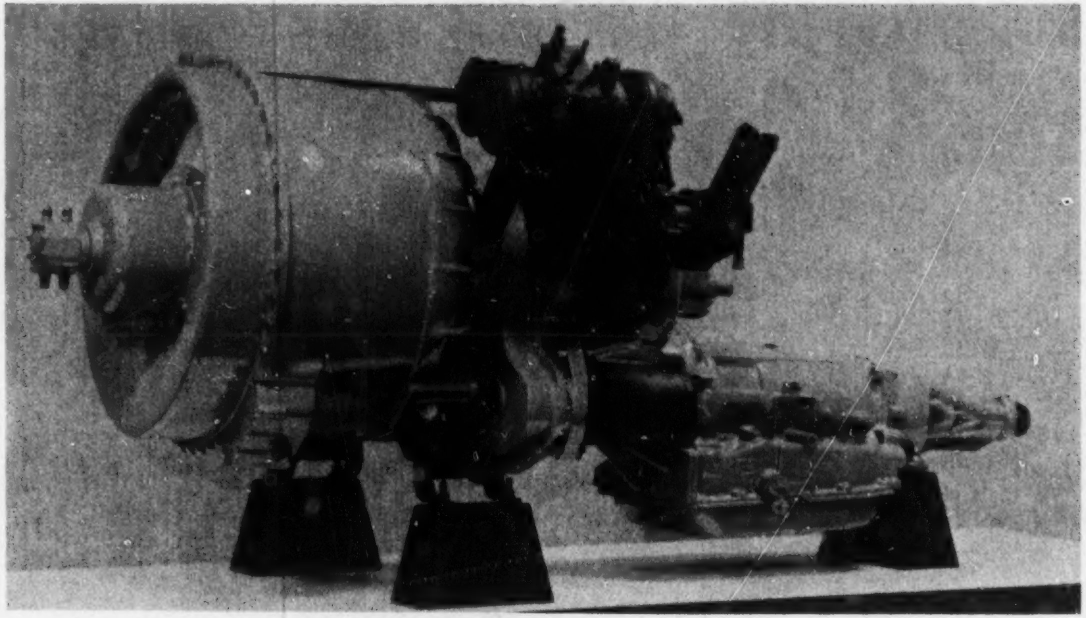
AGT PROGRAM SCHEDULE



MS 6707-11

Figure 8

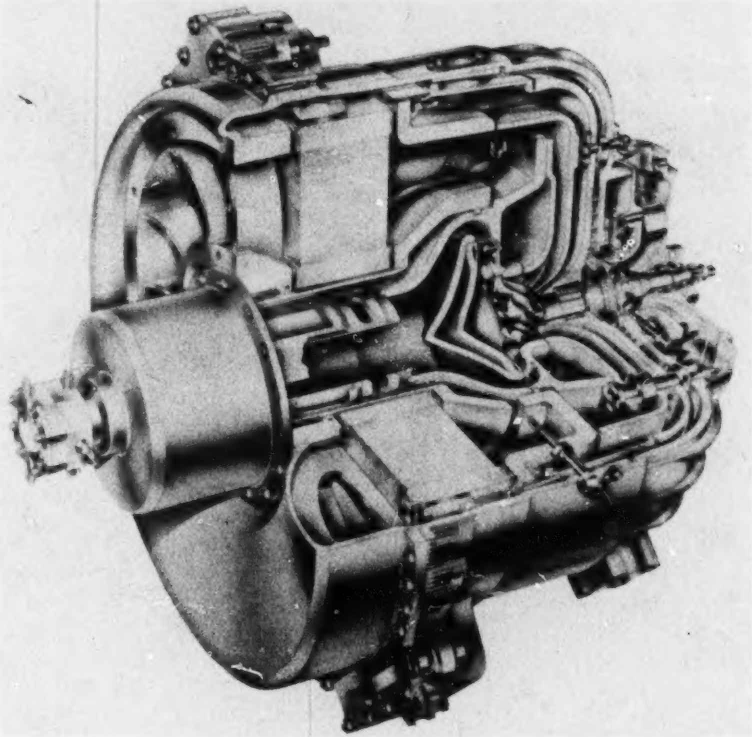
AGT101 POWERTRAIN



MS 6707-13

FIGURE 9

AGT101 POWER SECTION



MS 6707-14

Figure 10

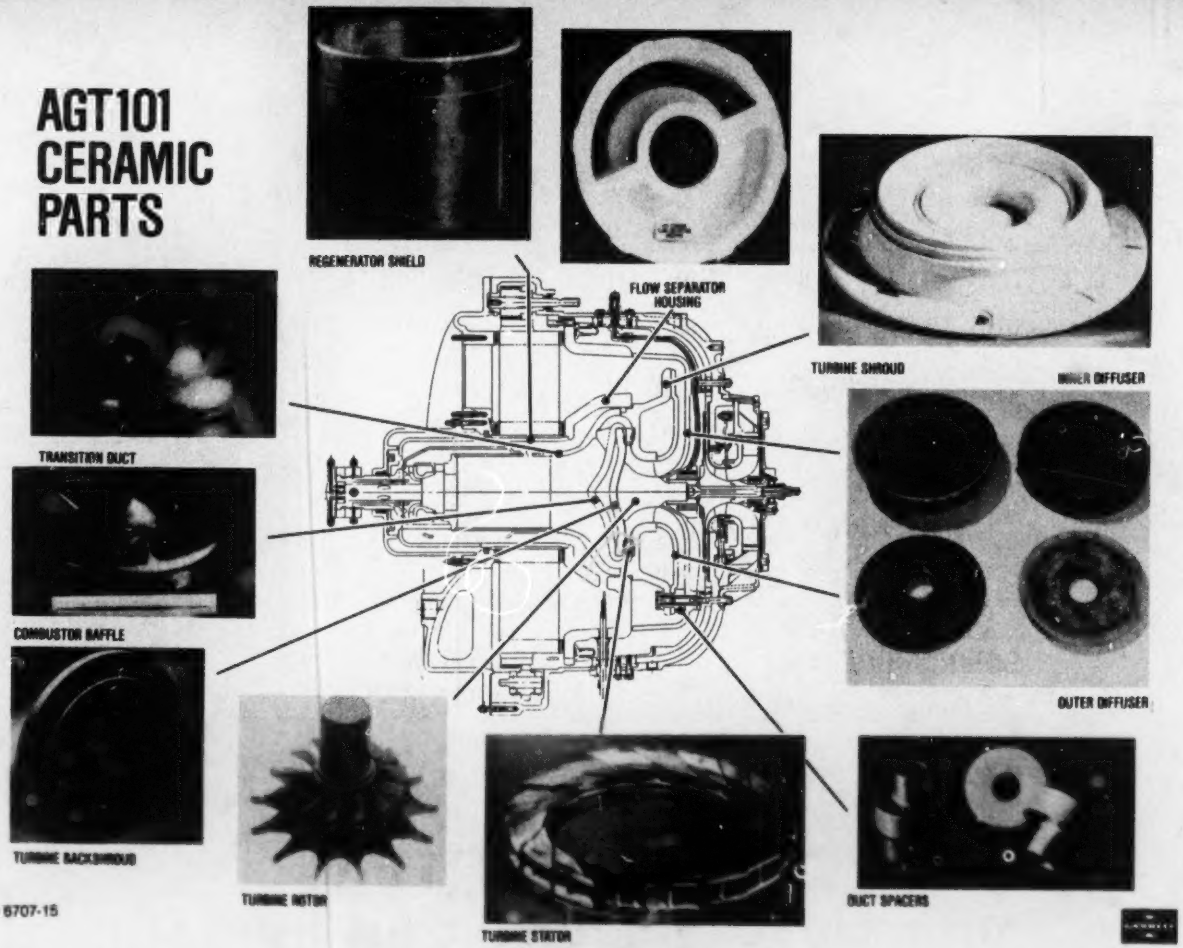

AGT101
CERAMIC
PARTS
REGENERATOR SHIELD
FLOW SEPARATOR HOUSING
TURBINE SHROUD
INNER DIFFUSER
TRANSITION DUCT
COMBUSTOR BAFFLE
OUTER DIFFUSER
TURBINE BACKSHROUD
TURBINE ROTOR
TURBINE STATOR
DUCT SPACERS
MS 6707-15

Figure 11

TYPICAL GAS TURBINE STRATEGIC MATERIAL USAGE

STRATEGIC MATERIAL	PERCENT IMPORTED BY U.S.	PRINCIPAL SOURCE OF U.S. SUPPLY
CHROMIUM	92	SOUTH AFRICA, ZIMBABWE
NICKEL	76	NORWAY, CANADA
COBALT	97	ZAIRE
TANTALUM	97	THAILAND
COLUMBIUM	100	BRAZIL, NIGERIA
MANGANESE	98	SOUTH AFRICA, SOVIET UNION
TITANIUM	35	ZAIRE, ZAMBIA

MS 6707-16

FIGURE 12

F-15/16 GAS TURBINE ENGINE

STRATEGIC MATERIALS

FOR 1 JET-FIGHTER ENGINE...

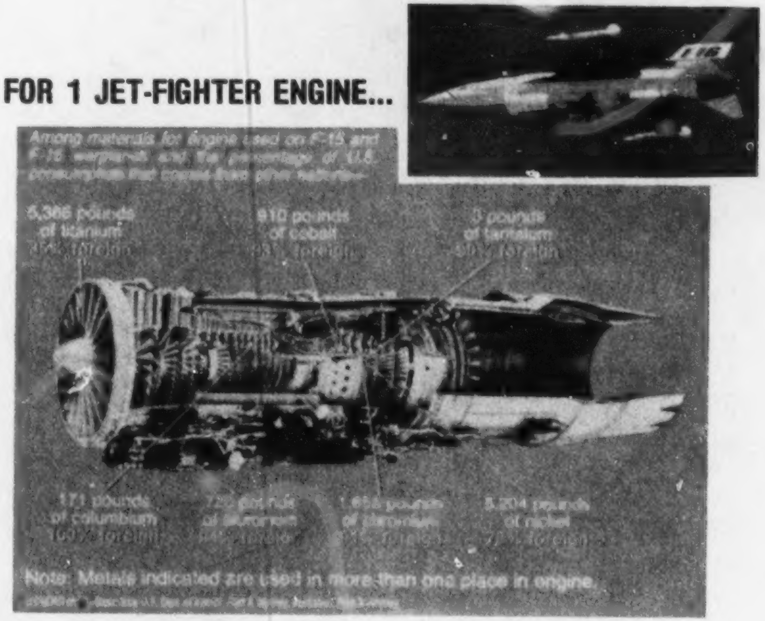

Among materials for engine used on F-15 and F-16 warplanes, and the percentage of U.S. consumption that comes from other nations—
5,366 pounds of titanium
910 pounds of cobalt
3 pounds of tantalum
171 pounds of columbium 100% foreign
5,204 pounds of nickel
Note: Metals indicated are used in more than one place in engine.

FIGURE 13

ABUNDANT ELEMENTS

EARTH'S CRUST	%
OXYGEN	50.0
SILICON*	25.7 **
ALUMINUM	7.3
IRON	4.2
CALCIUM	3.2
SODIUM	2.4
POTASSIUM	2.3
MAGNESIUM	2.2
HYDROGEN	0.95
TITANIUM	0.43
CHLORINE	0.21
CARBON*	0.19
PHOSPHORUS	0.11
SULFUR	0.11

ATMOSPHERE	%
NITROGEN*	77***
OXYGEN	22

*ELEMENTAL CONSTITUENTS OF CERAMICS SiC, Si_3N_4

**EQUIVALENT TO ABOUT 25.7 MILLION TONS/PERSON

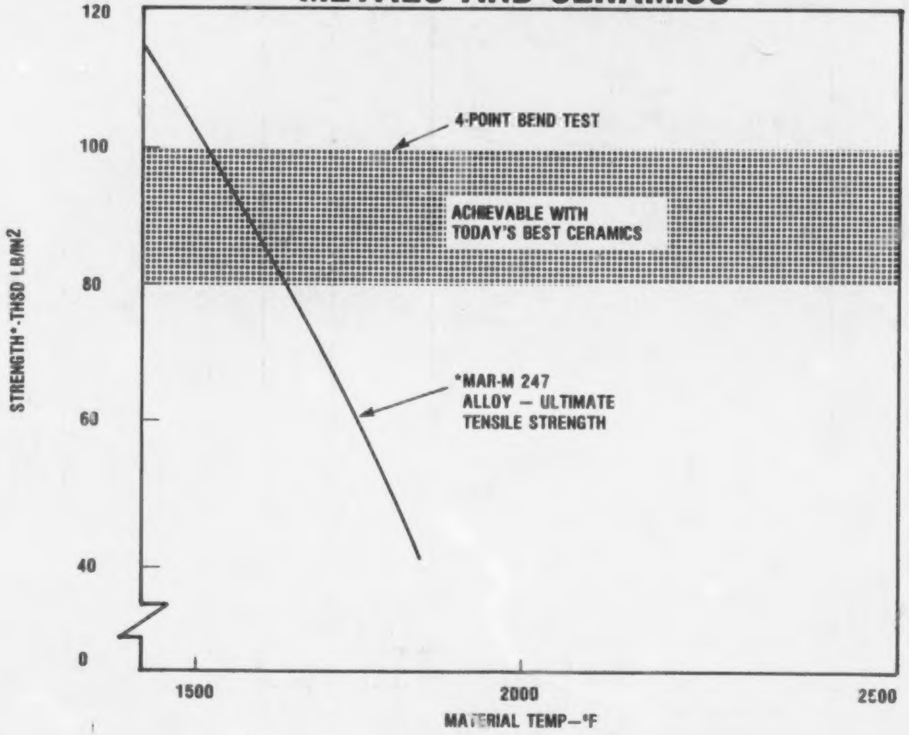
***EQUIVALENT TO ABOUT 1.1 MILLION TONS/PERSON

MS 6707-17

FIGURE 14

STRENGTH VS TEMPERATURE

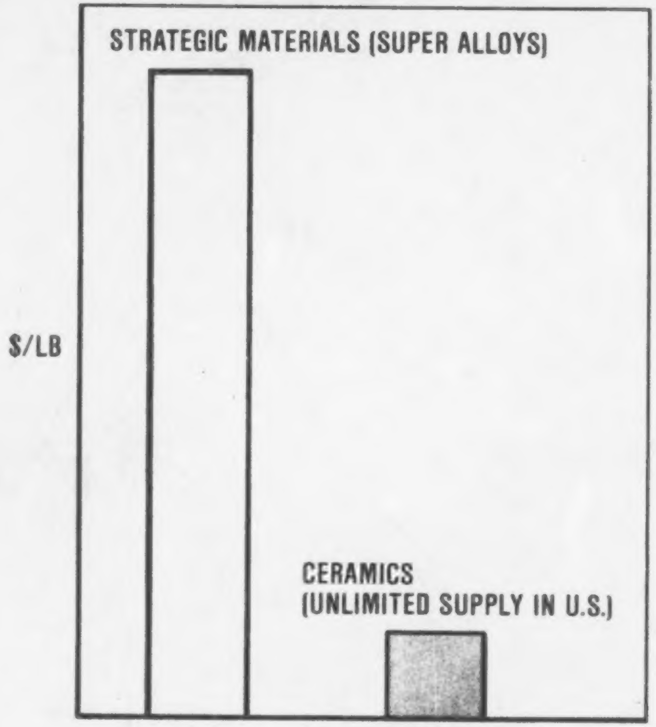
METALS AND CERAMICS



MS 6707-18

FIGURE 15

CERAMICS VERSUS STRATEGIC MATERIALS



MS 6707-19

FIGURE 16

U.S. CERAMICS ACTIVITIES

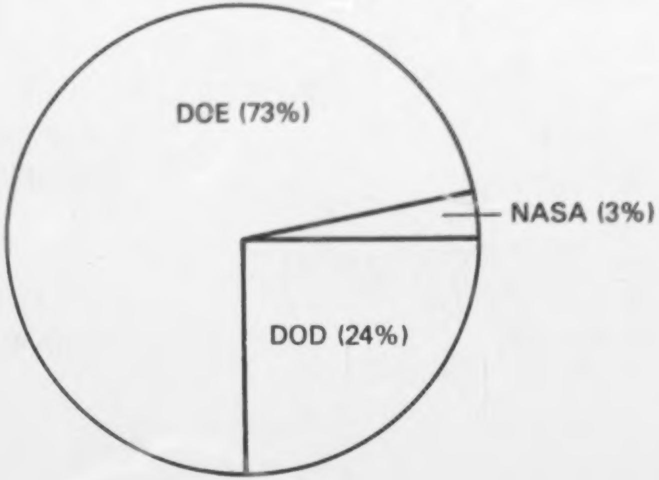
INDUSTRY TEAM	AGT 101	AGT 100
• FORD	✓	
• GTE		✓
• CARBORUNDUM	✓	✓
• CORNING GLASS	✓	✓
• AIRESEARCH CASTING COMPANY	✓	
• NORTON		
• COORS PORCELAIN		
• PURE CARBON	✓	

MS 6707-38

FIGURE 17

STRUCTURAL CERAMICS FOR HEAT ENGINES

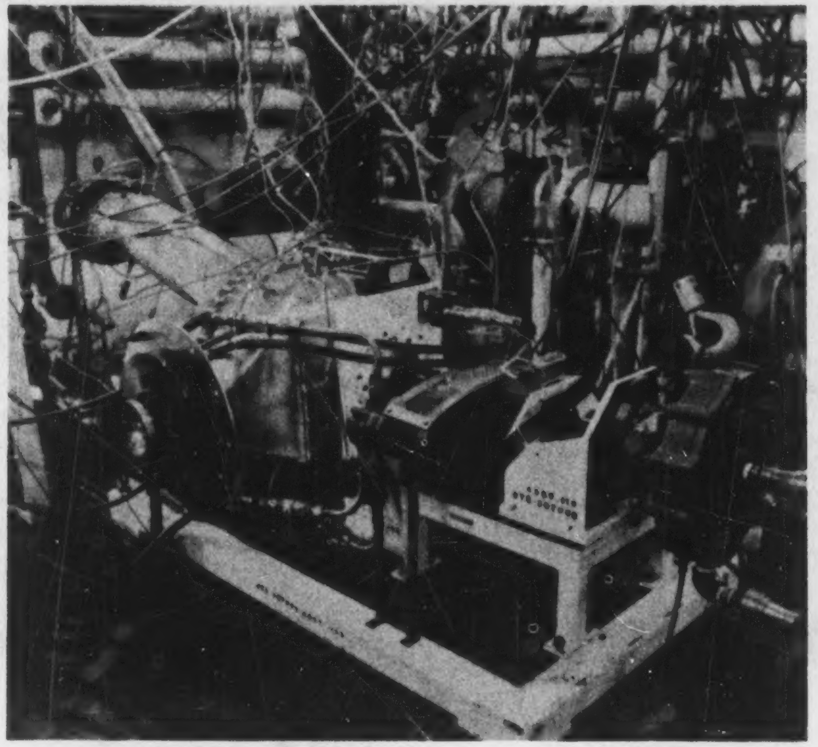
DISTRIBUTION OF U.S. GOVERNMENT FUNDED R&D FY1981



MS 6707-40

Figure 18

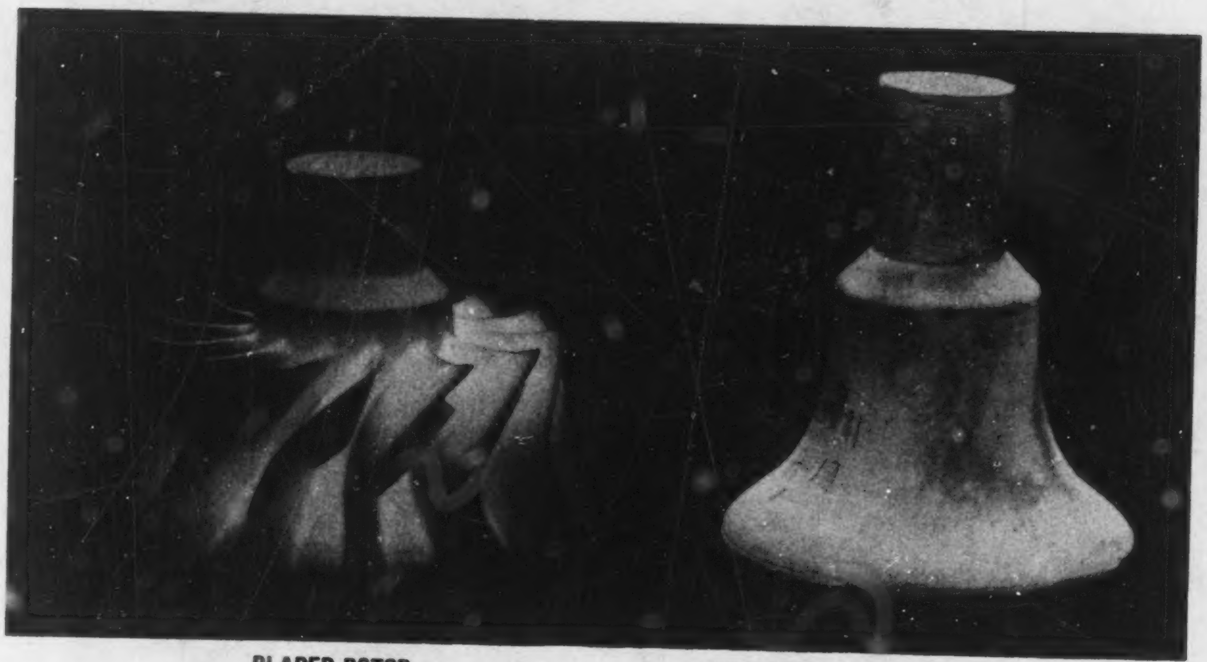
GARRETT/FORD AGT101 ENGINE TEST



MS 6707-20

FIGURE 19

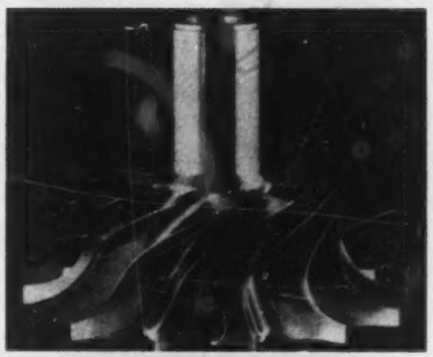
AGT101 TURBINE ROTOR APPROACH


BLADED ROTOR
SIMULATED ROTOR

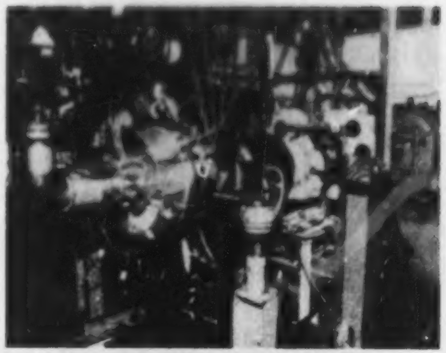
MS 6707-21

Figure 20

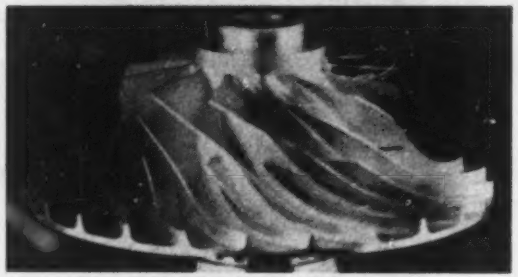
AERODYNAMIC RIGS



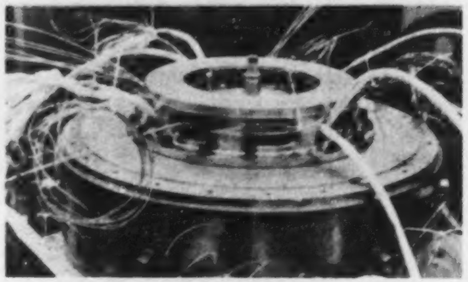
TURBINE ROTOR



COLD AIR TURBINE TEST RIG



COMPRESSOR IMPELLER

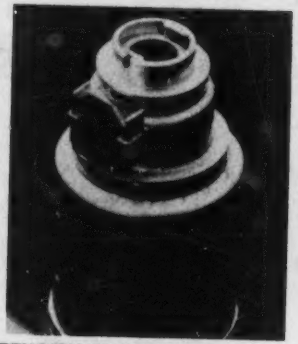


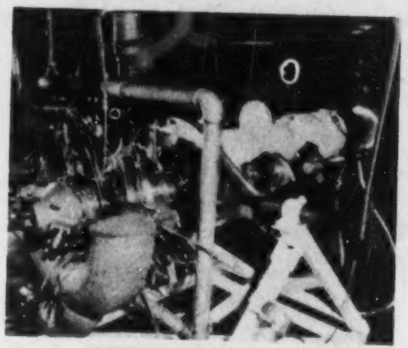
COMPRESSOR TEST RIG

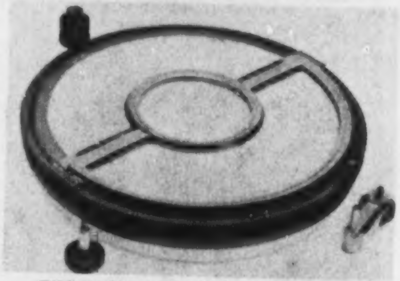
MS 6707-22

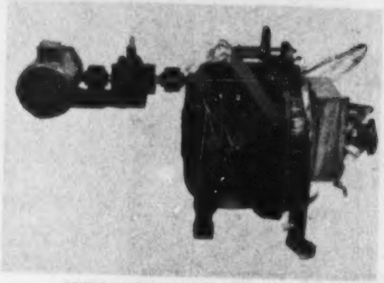
FIGURE 21

COMBUSTOR & REGENERATOR RIGS


DIFFUSION FLAME COMBUSTOR


COMBUSTOR TEST RIG

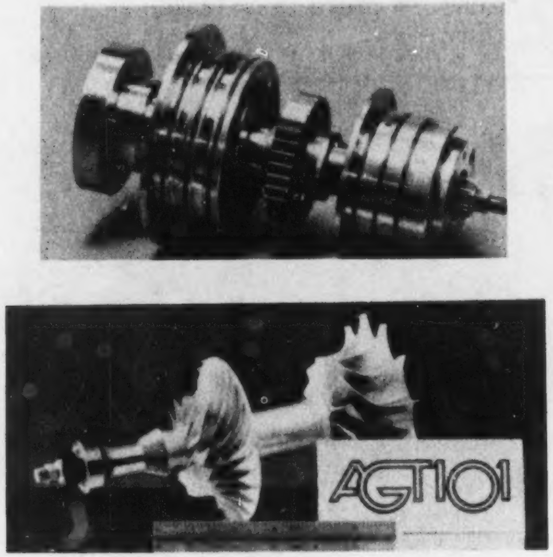

REGENERATOR CORE ASSMEBLY

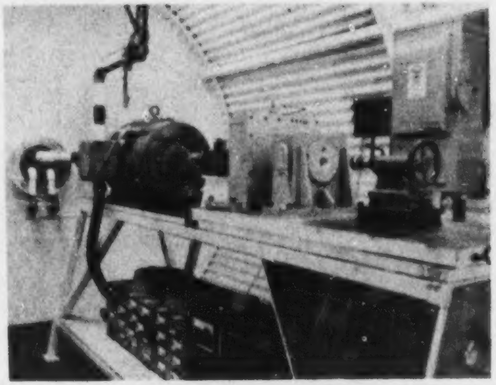

HOT REGENERATOR TEST RIG

MS 6707-23

FIGURE 22

ROTOR DYNAMICS RIG

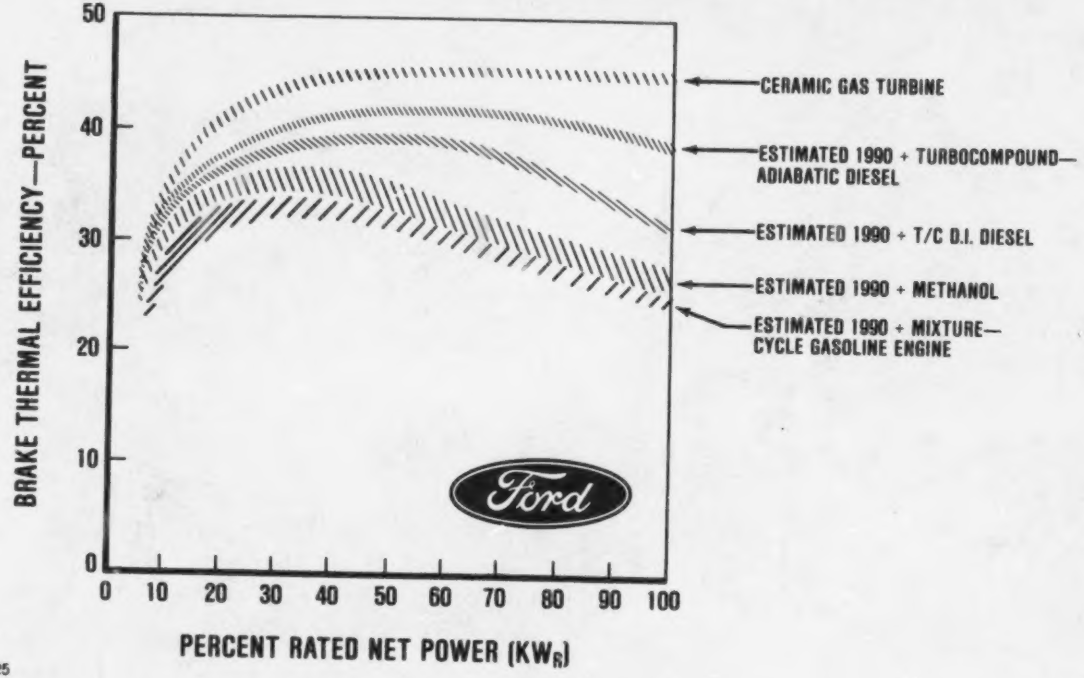




ROTOR DYNAMICS TEST RIG

FIGURE 23

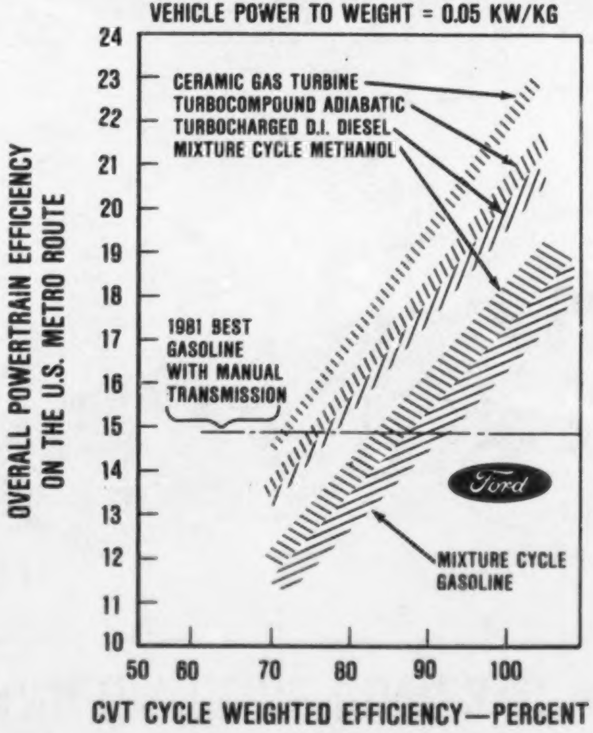
FORD COMPARISON OF 1990+ ESTIMATED ENGINE EFFICIENCY CHARACTERISTICS



MS 6707-25

FIGURE 24

FORD COMPARISON OF 1990+ ESTIMATED ENGINE CHARACTERISTICS ON THE U.S. METRO ROUTE



MS 6707-26

Figure 25

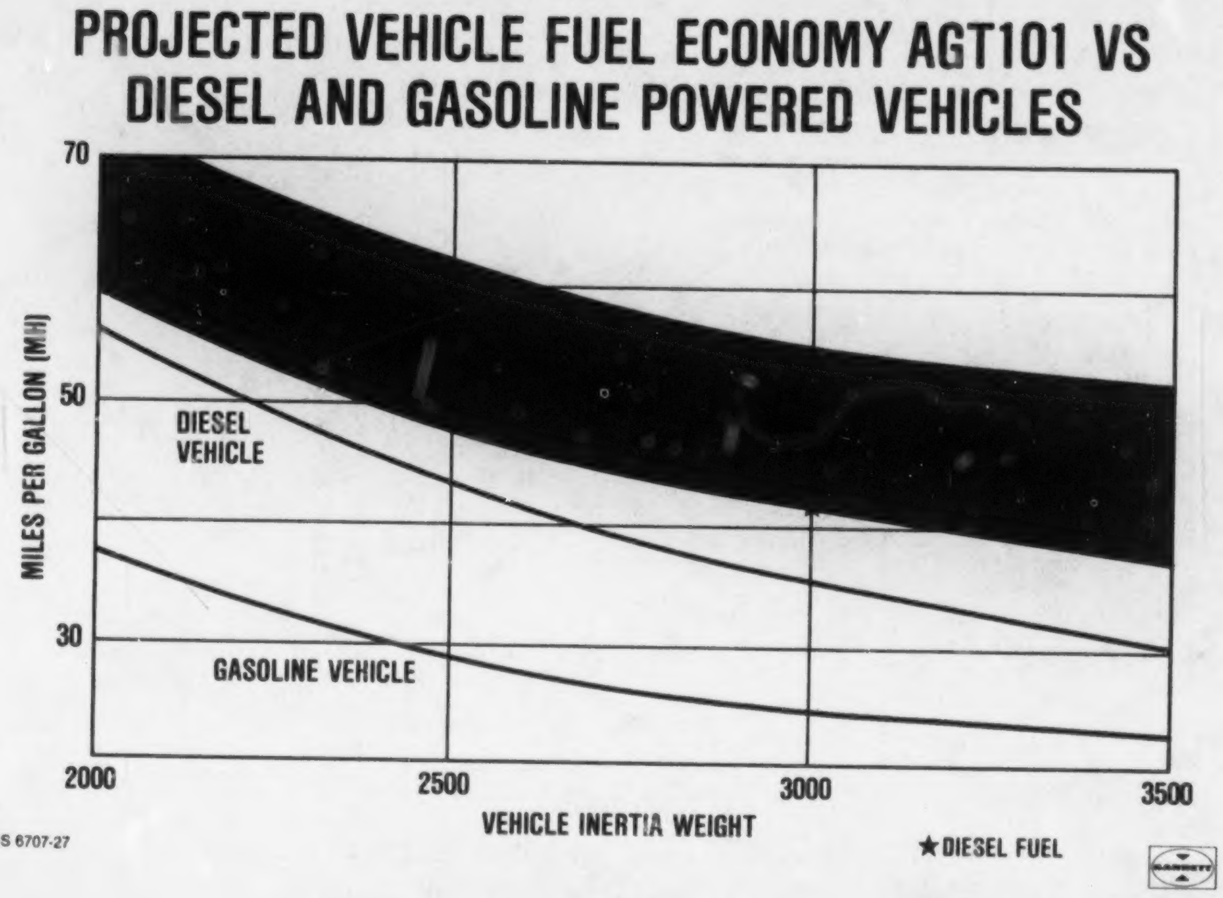
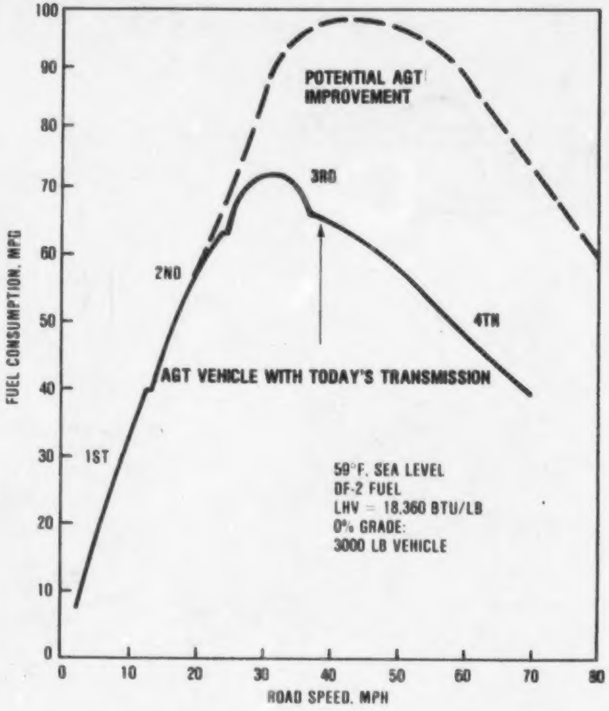

PROJECTED VEHICLE FUEL ECONOMY AGT101 VS DIESEL AND GASOLINE POWERED VEHICLES
70
50
30
MILES PER GALLON (MH)
DIESEL VEHICLE
GASOLINE VEHICLE
2000
2500
3000
3500
VEHICLE INERTIA WEIGHT
★DIESEL FUEL
MS 6707-27

FIGURE 26

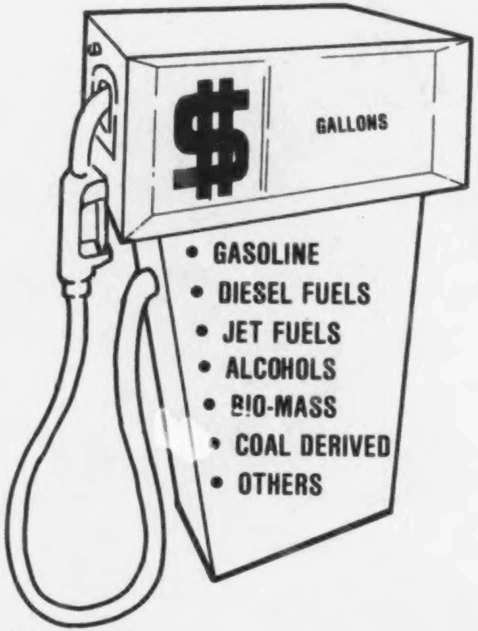
AGT101 IMPROVED STEADY STATE FUEL ECONOMY



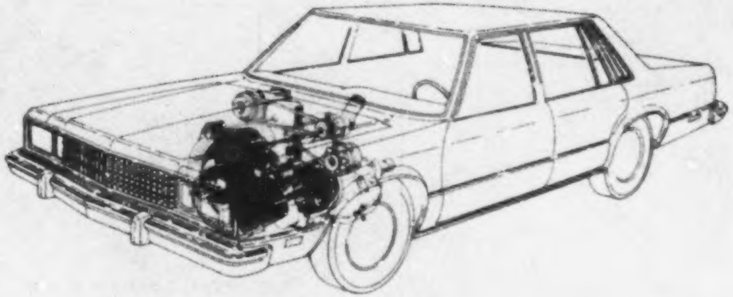
MS 6707-28

Figure 27

POTENTIAL AGT101 ALTERNATE FUELS



- GASOLINE
- DIESEL FUELS
- JET FUELS
- ALCOHOLS
- BIO-MASS
- COAL DERIVED
- OTHERS

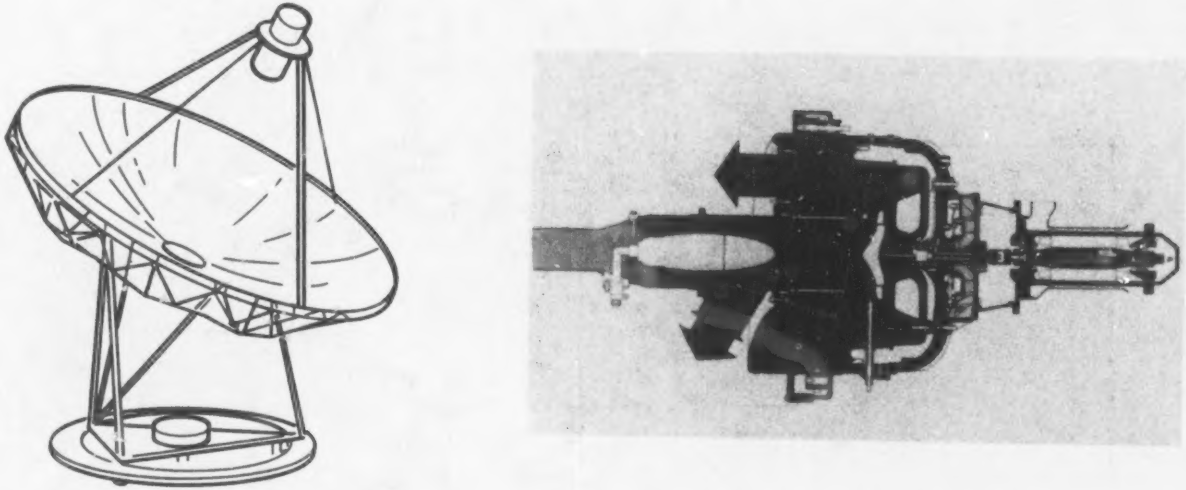


AGT101

MS 6707-29

FIGURE 28

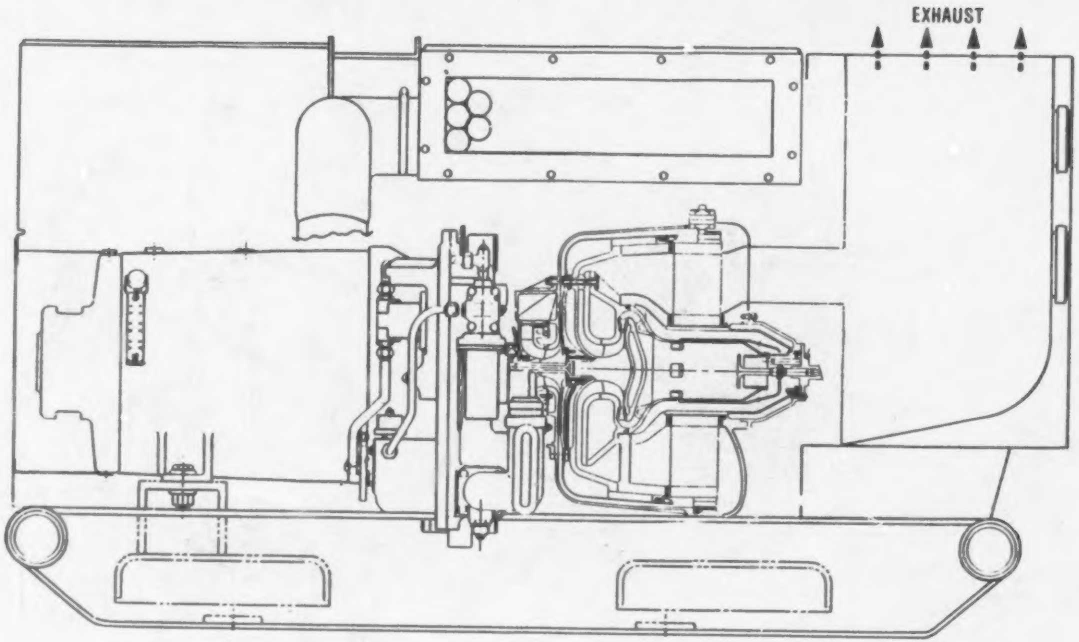
SOLAR AGT



MS 6707-30

Figure 29

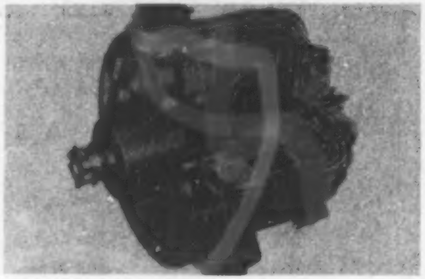
GENERATOR SET VERSION—AGT101



MS 6707-31

FIGURE 30

AGT-101 AIRCRAFT DERIVATIVE ENGINE



+

ADDITIONAL:

COMPRESSOR
INTERCOOLER
FREE TURBINE

=

**AIRCRAFT
DERIVATIVE
ENGINE**

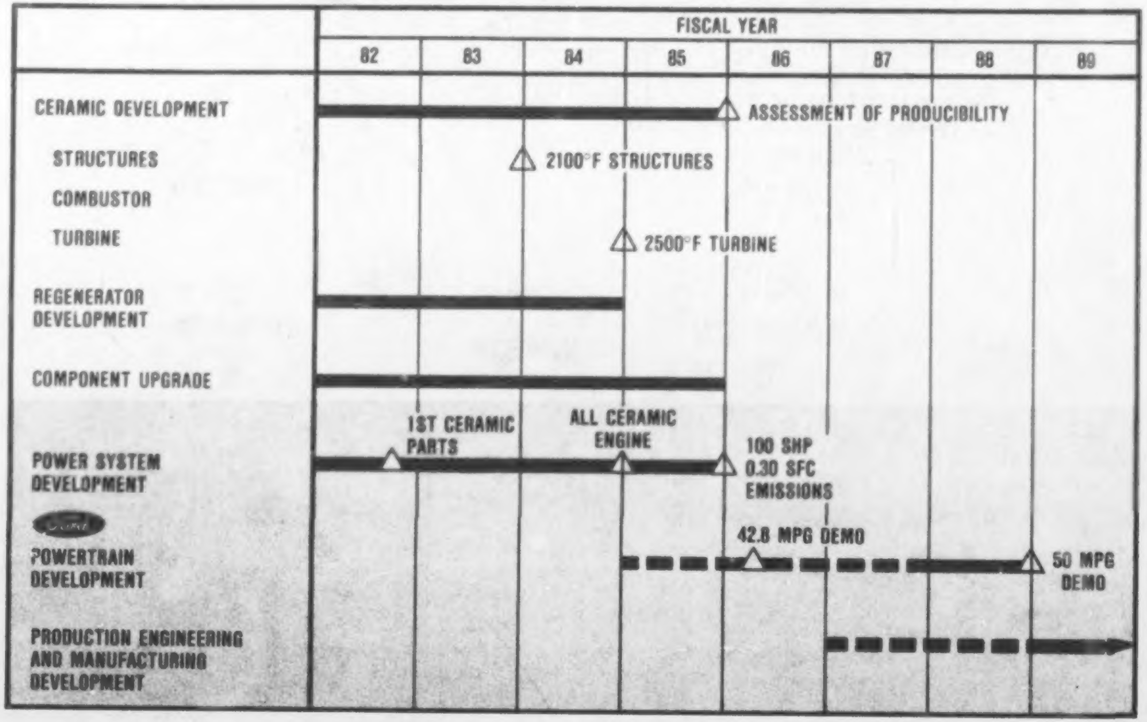
FEATURES

- LIGHT WEIGHT
- LOW COST OF OWNERSHIP
- LOW FUEL CONSUMPTION
- MULTIFUEL CAPABILITY
- LOW NOISE/EMISSIONS

MS 6707-33

FIGURE 31

RESTRUCTURED AGT101 PROGRAM



MS 6707-34

Figure 32

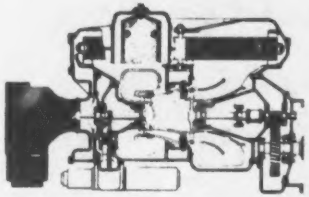
GERMAN GAS TURBINE AUTOMOBILE DEVELOPMENT PROGRESSING

(AUTOMOTIVE ENGINEERING, JANUARY 1982)

"CERAMICS ARE AN ADVANCED FEATURE OF THE MERCEDES GAS TURBINE, WHICH HAS AN INTEGRAL POWER TURBINE ROTOR HOT-PRESSED FROM SILICON NITRIDE. THIS HAS ALREADY BEEN TESTED FOR OVER 140 HOURS AT 60,000 RPM WITH COMBUSTION TEMPERATURES REACHING 1327°C (2420°F).

SUCH HEAT LEVELS ARE ACCEPTED AS THE KEY TO HIGH THERMAL EFFICIENCY AND A FUEL CONSUMPTION COMPARABLE TO PISTON ENGINES, AND D-B'S WORK IN THIS SPECIALIZED FIELD IS BACKED BY THE GERMAN FEDERAL MINISTRY AS PART OF ITS CERAMICS PROGRAM. TEMPERATURES UP TO 1870°C ARE NOW SEEN AS ATTAINABLE."

TWIN-SPOOL GAS TURBINE HAS CERAMIC POWER ROTOR THAT HAS BEEN SUCCESSFULLY TESTED AT UP TO 1327°C. ADJUSTABLE GUIDE VANES ARE OF SAME MATERIAL.



- ■ INTAKE NOISE DAMPER
- ☐ GAS GENERATOR WITH COMPRESSOR ROTOR AND COMPRESSOR TURBINE
- ■ HEAT EXCHANGER DISC.
- ◧ COMBUSTION CHAMBER
- ■ ADJUSTABLE GUIDE VANE
- ☐ POWER TURBINE ROTOR WITH TRANSMISSION

MS 6707-41

FIGURE 33

JAPANESE COMPANY READY TO PRODUCE CERAMIC CAR ENGINE

(DAYTON JOURNAL HERALD - JANUARY 22, 1982)

"TOKYO - A REVOLUTIONARY CERAMIC AUTOMOBILE ENGINE HAS BEEN DEVELOPED BY THE NGK SPARK PLUG CO. OF NAGOYA, AND THE COMPANY SAYS IT IS READY TO START COMMERCIAL PRODUCTION.

NGK'S CERAMIC ENGINE IS AN AIR-COOLED TWO-CYCLE 50cc TYPE. THE CYLINDERS, PISTONS, AND CRANKSHAFT ARE MADE OF CERAMIC. THE ONLY METAL PARTS ARE THE PISTON RINGS, BEARINGS AND BOLTS. THE ENGINE HAS PASSED AN ENDURANCE TEST DURING WHICH IT WAS RUN AT 3,000 REVOLUTIONS PER MINUTE FOR 50 CONSECUTIVE HOURS."

MS 6707-42

FIGURE 34

JAPANESE CERAMIC ENGINE UNVEILED

(BALTIMORE SUN - JANUARY 5, 1982)

"TOKYO (REUTER) - TWO JAPANESE COMPANIES YESTERDAY UNVEILED A CAR THAT THEY SAID CONSUMES 30 PER CENT LESS FUEL THAN CONVENTIONAL CARS BY USING AN ENGINE MADE OF CERAMIC SIMILAR TO THE LIGHTWEIGHT MATERIAL THAT PROTECTS THE U.S. SPACE SHUTTLE FROM THE ENORMOUS HEAT OF ATMOSPHERIC RE-ENTRY. THE DESIGNERS, ISUZU MOTORS AND KYOTO CERAMICS, SAID THE EXPERIMENTAL THREE-CYLINDER, 2,000-CUBIC-CENTIMETER DIESEL ENGINE WAS OF AN ENTIRELY NEW TYPE WHICH DID NOT NEED A COOLING SYSTEM. THEY SAID THE ENGINE, MADE OF NITRIDED SILICON TREATED BY INTENSE HEAT, COULD WITHSTAND HEAT OF MORE THAN 2,000 DEGREES FAHRENHEIT, WHICH WOULD BE ENOUGH TO MELT A METAL ENGINE."

MS 6707-43

FIGURE 35

JAPANESE GOVERNMENT INVOLVEMENT IN CERAMIC STRUCTURES

GOVERNMENT AGENCY	FUNDING $M	DESCRIPTION
MINISTRY OF INTERNATIONAL TRADE & INDUSTRY (MITI) - DEPARTMENT OF INDUSTRIAL SCIENCE & TECHNOLOGY	$95	"MOONLIGHT PROJECT" - A 7 YEAR, 5 SUBPROJECT, ENERGY SAVING TECHNOLOGY (ADVANCED GAS TURBINE) PROJECT BEGUN IN 1978.
MITI-DEPARTMENT OF INDUSTRIAL SCIENCE & TECHNOLOGY	$59	FINE CERAMICS PROGRAM. IN 1980, MITI ANNOUNCED A NEW (FINE) CERAMICS 10 YEAR R&D PROGRAM.
GOVERNMENT INDUSTRIAL RESEARCH INSTITUTE	UNKNOWN	THE INSTITUTE RECENTLY COMPLETED A UNIQUE CERAMIC BAKING FACILITY FOR THE PURPOSE OF DEVELOPING REVOLUTIONARY KINDS OF CERAMIC INDUSTRIAL MATERIALS.

MS 6707-44

FIGURE 36

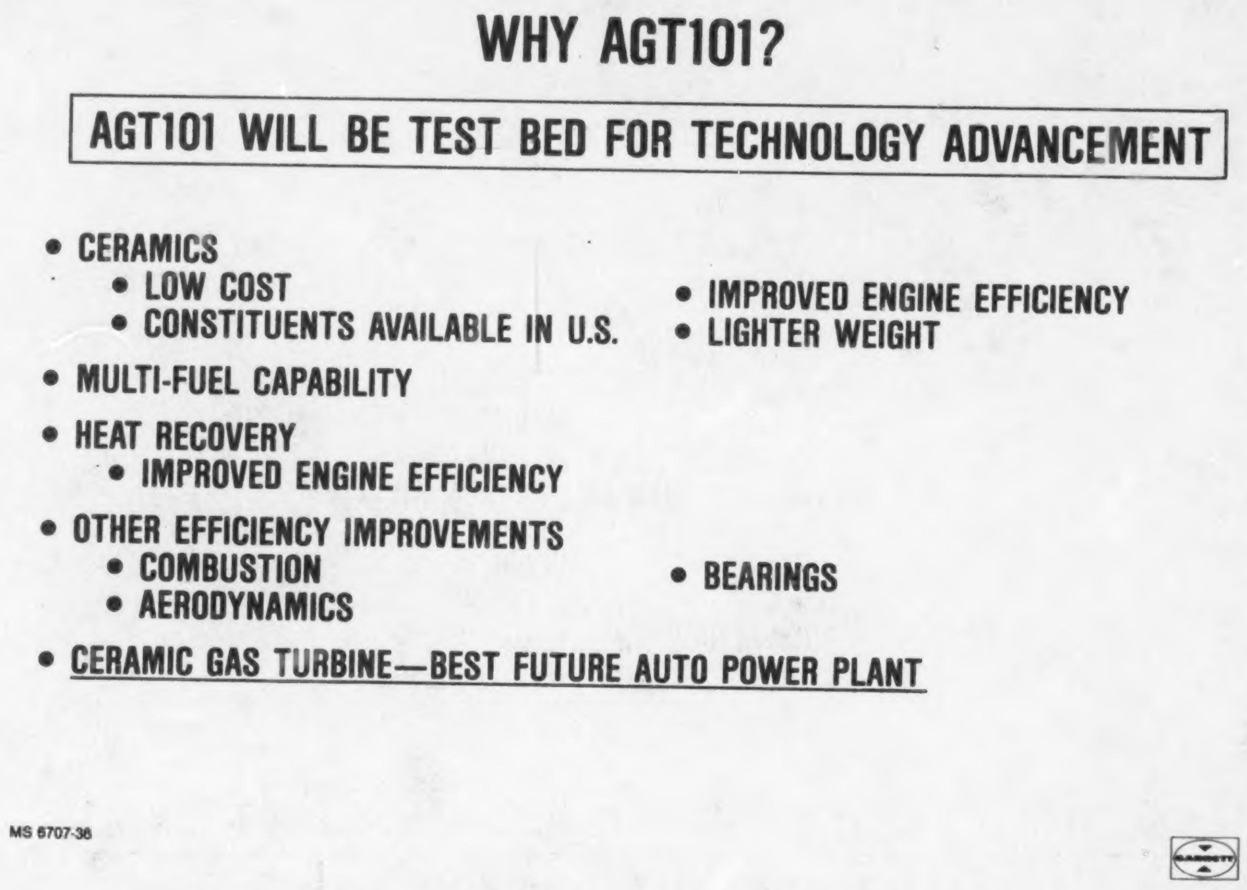
WHY GOVERNMENT SUPPORT?

ADVANCE LONG RANGE HIGH RISK POWER PLANT TECHNOLOGY

- REDUCE ENERGY CONSUMPTION
  - DEPENDENCE ON FOREIGN OIL
    - EXPENSIVE
    - RELIABLE?
- REDUCE NEED FOR STRATEGIC MATERIALS
  - SUPPLY BEING DEPLETED
  - EXPENSIVE
  - FOREIGN SUPPLY UNCERTAIN
- REDUCE EMISSIONS
- COMBAT FOREIGN COMPETITION

MS 6707-35

FIGURE 37



WHY AGT101?

AGT101 WILL BE TEST BED FOR TECHNOLOGY ADVANCEMENT

- CERAMICS
  - LOW COST
  - CONSTITUENTS AVAILABLE IN U.S.
  - IMPROVED ENGINE EFFICIENCY
  - LIGHTER WEIGHT
- MULTI-FUEL CAPABILITY
- HEAT RECOVERY
  - IMPROVED ENGINE EFFICIENCY
- OTHER EFFICIENCY IMPROVEMENTS
  - COMBUSTION
  - AERODYNAMICS
  - BEARINGS
- CERAMIC GAS TURBINE—BEST FUTURE AUTO POWER PLANT

MS 6707-36

FIGURE 38

Mr. **Glickman**. Go ahead, Mr. Ronzi.

Mr. **Ronzi**. Thank you, Mr. Chairman.

I am Richard Ronzi, director of powertrain research for Ford Motor Co.

Ford is very interested in the future of the advanced gas turbine program for a number of fundamental reasons:

First, the high temperature ceramic gas turbine is projected to be capable of being competitive with the most fuel-efficient future candidate automotive engines. In fact, our recent estimates indicate it may be the most efficient. In addition, the turbine is also in keeping with Ford's long-term objective to provide vehicles that can operate on a variety of alternative fuels.

Second, the ceramic technology that is the heart of the automotive gas turbine is not limited to the AGT applications. The successful development of this technology appears to have potential for spin-off to defense, manufacturing, new commercial product and other automotive applications.

These spinoff applications include the adiabatic diesel engines, diesel particulate traps, turbochargers, cutting tools, and reduced friction components. We are in the midst of a rapid growth in the capability to use ceramics, and new applications are certain to develop as the technology matures.

It must be recognized that both the AGT and its ceramic technology are high-risk programs. Problems remain to be solved, and while success cannot be assured, the accomplishments of past Ford/DOD/DOE/NASA efforts have been very substantial.

First, we have established the ceramic gas turbine as an automotive or stationary powerplant candidate. We have developed a successful ceramic regenerator system that has operated for more than 5,000 hours at 1,800° F., inlet temperature. The value of this has been noted by Japanese, European, and American corporations who have requested licenses.

We have also developed fundamental high strength ceramics that, in bench tests, have achieved 100,000 pounds per square inch strength at 90 percent reliability. These ceramic parts, and the test bars I have here, provide some indication of the progress that has been made. After I complete the testimony, I would like to show you the bars, if possible.

Other nations have not been idle. Major programs exist in Germany and Japan to exploit the capability of ceramics. If the U.S. ceramic programs are not adequately funded, there is a major risk that the United States will lose its lead in this area.

In summary, the Garrett/Ford ceramic AGT 101 program provides an excellent focal point for the development of the world's most efficient automotive powerplant, and it provides the stimulus for continuous progress in the U.S. ceramic technological capability. We believe that every effort should be made to continue the support for the automotive ceramic gas turbine program, specifically the AGT 101.

Thank you.

[Whereupon, Mr. Ronzi presented demonstration products to the Congressmen.]

Mr. **Ronzi**. Now, to me, a mechanical engineer, the whole process of ceramics is somewhat amazing. We start with, essentially, a bag of processed sand.

Mr. **Glickman**. I must tell you, Mr. Ronzi, when I visited the Garrett facility, I put my fingers on some of the ceramics, and I am not sure you want me to touch them, because I think I set the program back 2 years. I dropped half the pieces. [Laughter.]

Mr. **Ronzi**. Well, you may want to try just these test parts. There is one for each of you. The challenge is to see if you can break it in half.

You know, you can tell by these samples that it is an amazing material that has been developed. At the same time, it is strong. It will also withstand 2,500 degrees, as this part has done, for more than 5 hours. It is in essentially brand new condition.

So we are really talking about some amazing technology. I probably should take those back. My ceramic wizards need these treasures. Thank you.

Mr. **Glickman**. Thank you.

The statement was made, by Mr. Boppart, that ceramics cannot be developed independently of the environment in which they will be operating. By that, do you mean that you just cannot do generic work in ceramics; it must relate to something?

Mr. **Boppart**. That is right. The properties and the success of achieving the properties are so dependent on the actual size, shape, and operating environment in which they are going to be used, that we strongly feel that the only realistic way to conduct development, is in something which closely approximates the kind of engine that the technology is going to be applied in.

Mr. **Glickman**. Also in your statement, you indicated that the DOE/NASA AGT and related programs are the only significant source of Government funding for this critical technology development. You talked about the fact that ceramics may in fact replace critical materials.

Do you know if anybody else in Government is doing any work in ceramics?

Mr. **Boppart**. There is some DOD-supported work, but in fact the reason that there is not more is because of the fact that the major effort is going forward under this DOE/NASA program.

Mr. **Glickman**. Do you have any reason to believe DOD will go ahead with additional ceramics work if this program ends?

Mr. **Boppart**. No.

Mr. **Glickman**. So, in fact, irrespective of the relationship to the auto industry and engine technology, we will basically be eliminating our ceramics work throughout the U.S. Government if this program is terminated?

Mr. **Boppart**. That is correct.

Mr. **Glickman**. And I think your statement indicated that significant work was being done in ceramics relating to engines in both Germany and Japan.

Mr. **Boppart**. Yes.

Mr. **Glickman**. If the AGT program could be continued through completion, will the risks be quantified sufficiently for industry to proceed into product development, and what would be the most likely first application? Either one of you gentlemen might want to comment on that.

Mr. **Ronzi**. Well, I probably can take that question.

We have constructed the program that was shown in the slide to really accomplish the durability and reliability objectives on the dynamometer, and we feel, if those capabilities are established, we would be in a position to proceed toward production, assuming all other economic and political and social factors make that the right thing to do.

There are also, quite honestly, other competing engine candidates out there that may develop, and at the time we reach the end of the program we would obviously rank and compare all of the existing candidates. But assuming success and assuming no other candidate is more promising, then we would be in a position to pick that program up and go toward a production application.

Mr. **Glickman**. If the program is terminated, what are you going to do?

Mr. **Ronzi**. We really have not thought through that in enough detail to give you a good answer. We are still attracted by the gas turbine, and we would always try to find a way to keep the program alive. Whether or not we can find the resources is impossible for me to say today. I think we would make every effort to keep the program alive, but with our other pressures for nearer term research and development, it may not be possible.

Mr. **Boppart**. From Garrett's side, we would definitely not be in a position to be able to continue the program on anything remotely approximating this level of advancement because of the current economic climate and the very high risk associated with this very promising technology.

Mr. **Glickman**. So you both might continue some research, but it would clearly be on a decelerated schedule.

Mr. **Boppart**. Very much so.

Mr. **Glickman**. And I forgot what your vu-graphs showed. How much were the Japanese spending in ceramics-related work? You had a MITI figure, I think.

Mr. **Boppart**. It is about $150 million.

Mr. **Glickman**. One-hundred and fifty million dollars on an annual basis, or is it a total figure?

Mr. **Boppart**. It is a multiyear program.

Mr. **Glickman**. So it would be roughly at the same level, then, at which you were proceeding.

Mr. **Boppart**. Yes; well, roughly at the same level. The total Government investment in all programs, really.

Mr. **Glickman**. We hear a lot about industry cost sharing. Can you give me an idea of how much of your own money you have put into the project, both Ford and Garrett?

Mr. **Boppart**. So far, Garrett has put over $1 million of our own money into the program as far as we have gone, and our share will continue to increase.

Mr. **Ronzi**. I cannot give you quite a specific number, but I know it is in excess of $600,000 through the first portion of this program. It is beyond what we had originally committed to in our Government cost-sharing program.

Mr. **Glickman**. I am going to ask a final question and turn it over to Mr. Dunn. This is a leading question. You can answer it as you deem appropriate. Representing American industry, you have a stake in having profits in the future, and selling engines and cars. You do not agree with the administration's efforts to zero out these programs. Is that a fair statement?

Mr. **Ronzi**. I think it is; yes. I think we feel that this is fundamental technology and can have many applications throughout the United States. Maintaining our technical lead and being ready to introduce ceramic gas turbines is a very important program, and we feel it is an area the Government can provide some useful and directed funding.

Mr. **Glickman**. Mr. Boppart, would you agree with that?

Mr. **Boppart**. I certainly agree. I think, as we have shown, that this technology has such wide application, as Dick has pointed out, in nongas turbine applications. The very wide range of gas turbine potential uses, I think, makes it extremely valuable to the country's future, and I think it would be most unfortunate if this opportunity were to be lost.

Mr. **Glickman**. And is it a fair statement to say that if we drop our commitment, the Japanese are not going to follow suit?

Mr. **Boppart**. I think that is a very fair statement.

Mr. **Glickman**. I would like to ask Mr. Ronzi of Ford a final question. Are you doing any work on the Stirling engine?

Mr. **Ronzi**. We are not currently working on the Stirling, although we do follow its development.

Mr. **Glickman**. Might you reconsider your initial decision to pull out of the DOE program based upon maybe the initial results of MITI?

Mr. **Ronzi**. It is possible, if the developments of one program or another are very attractive, that we would be able to go back into the Stirling or any other program.

Mr. **Glickman**. OK. I thank you both.

Mr. Dunn?

Mr. **Dunn**. Thank you, Mr. Chairman.

You talked about 90 percent reliability. Can you explain that to me?

Mr. **Ronzi**. One of the major problems with ceramics is the ability to have every part be as good as the next part. So what we are basically saying, with a 90 percent reliability, is if we would build 100 parts, 90 out of 100 would have a strength that was above 100,000 p.s.i., and the other 10 percent would be somewhat below that. When we would design the engine, we would have to design for probably 99.9-plus percent reliability, so our design strength would be something below 100,000. But it just gives us an engineering index to the strength and the consistency from part to part.

Mr. **Dunn**. You are saying we now have 90-percent capability in design and we have to get to 99.9 percent?

Mr. **Ronzi**. This material has the laboratory strength to do the job we need to do in the ceramic gas turbine. What has to be done now is to be able to duplicate this laboratory strength in an operating turbine wheel. So it is transferring the test bar technology into a bladed wheel and proving that it really can operate in the engine environment and that we can produce turbine wheels with 90 and above percent reliability.

Mr. Boppart. I think it might be worthwhile expanding on that just a little bit. It is a unique characteristic of ceramics that the strength of a part is dependent on its size. If we were talking about a metal part and we got a certain strength in a sample like that, we would confidently expect that we can make a part the size of this table and it would have the same strength.

That is not true in ceramics. The larger the part gets, the higher the probability of somewhere having a flaw that reduces its strength. At the beginning of this program, it was recognized as the most challenging aspect of it to be able to retain this high strength in a part as big as the turbine rotor. The progress that has been made to date is really outstanding in comparison to, I think, anybody's expectations at the beginning of the program. It is one of the reasons that we feel so encouraged about the future potential of this technology.

Mr. Dunn. Well, regardless of whether it is a whole engine or just a turbine fan wheel portion of it, are you saying that 1 out of 10 engines coming down the assembly line today would not run?

Mr. Boppart. No.

Mr. Ronzi. No, no; no way; 90 percent is only an engineering index. With ball bearings, we use something called B-10 life. It is only used as a convenience. It does not mean that 10 percent of the bearings will fail, but it gives you a rule of thumb or a way to do your design job. We obviously will design for engine reliability that is certainly less than—we target for very small fractional failure rates.

Mr. Dunn. The chairman was talking about the future, and you said there are other engine possibilities, but there are also economical and political considerations. Some of those economical considerations have to be the plant costs of changing from a conventional engine to a gas turbine engine. Is that economically feasible in the next 10 years or not, regardless of how good the engine is?

Mr. Ronzi. I am not in the profit area of our business, but we have made dramatic changes in the size and shape of our cars. We have invested in new-style transmissions. We are investing in new engines today. Those are relatively gigantic investments, in my understanding of money, and if we have done it today and if profits are reasonable in the future, I would think there is a good opportunity to reinvest into a gas turbine engine in the nineties.

Mr. Dunn. The chairman also asked the question about if funding did not continue, what would happen to the program. I know you do not have the exact figure, but what, approximately, is Ford Motor's budget for R. & D. on basic research such as this?

Mr. Ronzi. The only number I have covers our total research and development effort. In 1981, we spent $1.7 billion on research and development, all the way from research into the final development of our products. So I really am not in a position to break it down any finer than that.

Mr. Dunn. Yes; I understand the $1.7 billion. I realize that a large percent of that is design work and near term; nevertheless, I do have some concerns about a $1.7 billion budget and a commitment on the part of Ford Motor Co. for approximately $600,000. I am not sure that indicates a real commitment for this program in terms of the Government money that has been put into it.

Mr. **Ronzi**. I think you should realize there are quite a few competing technologies. The distinct difference between the gas turbine and some of the others is the degree of risk involved. There are some nearer term technologies that have much lower risk and a much higher probability of success. When we do our budgeting, we naturally have to lean on the things that have a nearer term production need, and so this becomes a priority issue rather than anything else.

Mr. **Dunn**. If we design legislation in reporting out the budget that said we will continue funding, but that we request 25- or 50-percent commitment or whatever in 1982 dollars from Garrett and Ford, what would be your reaction to that?

Mr. **Ronzi**. I would not be in a position to react, to be honest with you. I am sure we would give it some thought, but whether we would be able to contain the expenditure, I really do not know today.

Mr. **Dunn**. If you could supply that kind of information to me, I think it would make our case more feasible to say we do have a commitment from Ford and Garrett that if we fund *x* million dollars, they will also put *x* million dollars into the project this year. If I could get a relative idea of your position on that, it would be appreciated.

Mr. **Ronzi**. All right.

Mr. **Dunn**. I thank you both.

Mr. **Boppart**. I think the context in which we would want to respond to that and the point that we want to make is that our willingness to invest in it is directly related to the proof of the technology. We feel that the program is currently in a state where, although the results are very, very promising, the risk of ultimate success is still very high, and we think that that is an appropriate area in which the Government should support the development of technology.

Mr. **Dunn**. I would agree with you.

Mr. **Boppart**. As we indicated, when we get to the point where the technology is proven, both in terms of Garrett's interest and Ford's interest, we recognize that then the responsibility is essentially entirely ours to implement it into actual practice.

Mr. **Dunn**. Yes; I am agreeing with you completely. I am just saying that it would be meaningful to this committee to have a commitment from you; it would be very helpful in that effort if your two companies also said, you give us this and we will firmly commit for 1982 a certain number of dollars.

So if I could have some of that kind of information, I would appreciate it.

Mr. **Boppart**. OK.

Mr. **Dunn**. I thank you very much.

Mr. **Glickman**. I want to thank you both for your excellent testimony.

Our next witness is Mr. Hillard Barrett.

Mr. Barrett, it is a pleasure to have you here today. You may proceed as you deem appropriate. Your entire statement will appear in the record.

STATEMENT OF HILLARD E. BARRETT, CHIEF ENGINEER, INDUSTRIAL GAS TURBINE ENGINES, DETROIT DIESEL ALLISON DIVISION, GENERAL MOTORS CORPORATION

Mr. **Barrett**. Thank you, Mr. Chairman.

I am Hillard E. Barrett, chief engineer for industrial gas turbines at the Detroit Diesel Allison Division of General Motors Corp.

Since 1976, DDA has been working with the Department of Energy on programs authorized by Congress under the Heat Engine bill, Public Law 95-238, with the objective of accelerating advanced automotive technology in the interest of fuel conservation. These programs have come under my purview.

I thank you for this opportunity to discuss once again Detroit Diesel Allison's participation in the Department of Energy's development program for an advanced gas turbine powertrain system for passenger cars.

You may recall that, 2 years ago, I reviewed for this subcommittee our goals and obligations under a contract we had just signed with NASA. Today I will review the progress we have made thus far, an outlook of the program potential, and some views on the value of the technology being developed.

While our program is funded by DOE, our contract has been issued by the National Aeronautics and Space Administration's Lewis Research Center, who manage the heat engine projects for the DOE. The goal of the program is to develop the advanced technology required for a gas turbine powertrain system that has significant improvement in fuel economy over that presently predicted for a 1985 conventional spark ignition engine.

Specifically for General Motors, the goal is to demonstrate a proof-of-concept gas turbine powertrain that meets the following objectives when installed in a 1985 Pontiac Phoenix having an inertia weight of approximately 3,000 pounds:

First, fuel economy of 42.5 miles per gallon, which is based on EPA test procedures, with driveability and performance comparable to a 1985 Phoenix with a spark ignition engine.

Second, low gaseous emissions and particulate levels.

Third, demonstrate that the gas turbine can use alternate fuels.

In addition to these primary objectives, there are several system design objectives to be evaluated during the program. These are:

One, competitive initial and life cycle cost.

Two, competitive reliability.

Three, acceleration characteristics that take into account safety considerations and consumer expectations.

The last is noise levels and safety characteristics required to meet currently legislated or projected 1985 Federal standards.

To achieve these ambitious goals, it is necessary to develop highly efficient small scale components and to operate the high temperature parts of the gas turbine several hundred degrees hotter than acceptable for currently available materials.

The program, therefore, concentrates on the research and technology of small scale aerodynamics. It also concentrates on the development of ceramic technology for the high temperature parts of the engine to replace metal superalloys used in all gas turbines today. It is this ceramic technology that is the essence of our program and can have the greatest national value.

On March 25, 1981, Mr. H. L. (Pete) Smith, who is vice president of General Motors and general manager of the Detroit Diesel Allison Division, addressed a letter to this subcommittee which I will quote in part:

> The materials under development are primarily silicon carbides, silicon nitrides, and aluminum silicates, all made of elements readily available in the United States. They contain no strategic elements such as cobalt, chromium, nickel or tungsten, which are essential for the superalloys but the availability of which is a growing cause of concern in the United States.

He went on to say:

> The U.S. Government, through DOE funding, has stimulated industry to address the basic development of a technology which promises to have far-reaching international impact, at a time when risk is high and demands for American corporate funding are at unprecedented levels. It is worth noting that structural ceramic technology is also being vigorously pursued in Germany and Japan. Continuing effort in this important materials technology is required to maintain a competitive position in the United States.

Progress in the development of the AGT 100 has been encouraging. The first series of aerodynamic component tests has now been completed. Initial efficiency goals have been attained, indicating that the aerodynamic scaledown will not cause a shortfall in performance. The path that has been outlined for aerodynamic development still appears appropriate and should be continued.

The advances in ceramics technology have also been promising. All of the parts and unique shapes required for the AGT 100 have now been fabricated. We have successfully rig-tested ceramic combustors and regenerators at near-goal temperatures. Ceramic turbine rotos have been spun consistently at 110 percent of design speed, whereas, 1 year ago, the average capability was less than 50 percent.

Our major subcontractors, Corning, Carborundum, and GTE, have responded with developments in material strengths, quality, nondestructive inspection techniques, and process development beyond that projected for this time period.

However, the infrastructure of the ceramics industry is still small and tenuous. There is no existing market to support the expensive R. & D. required of ceramics companies. Continued support and encouragement are essential to maintain vitality until such time as proof of concept is demonstrated.

As a result of the excellent progress we have made in component research and ceramics technology, we are now ready to run the complete engine. Parts for the engine are almost complete. The first build, which will include many rig-tested ceramic components, is scheduled for testing at midyear. Included in this first engine will be the ceramic combustor, turbine vanes and inlet plenum. Data from the first run will be an important milestone in the AGT 100 program.

Production cost and required capital investment will also be elements of paramount importance in the final evaluation of the viability of the gas turbine as an automotive engine. The accommodation necessary between cost and performance is present in most engineering developments and is certainly not new to the gas turbine.

From the very onset of the AGT 100 program, a team of project, manufacturing, and process engineers have been working closely together to assess the costs at every stage of development and participating in the design itself with recommendations to minimize labor, minimize material or machine costs, and to insure that the technology developed and demonstrated has the potential of meeting reasonable cost targets.

The studies to date have indicated that the current AGT 100 engine could be introduced at approximately the same premium as the diesel engine now commands. Furthermore, manufacturing experience should help to reduce the premium, particularly if the ceramic components can realize the cost savings promised by high volume production methods such as injection molding and extrusion.

On the schedule and funding, the AGT 100 project originally consisted of two phases over a 68-month period. Phase I of our contract was scheduled for 45 months and was estimated to cost $47 million. It concentrated on design and technology development of components and ceramic materials and the testing of the gas turbine powertrain system.

Phase II continued with the development of a redesigned and updated powertrain system with added emphasis on testing in both mobile and stationary test vehicles. Phase II was scheduled to run an additional 23 months and cost approximately $18 million.

From the start of 1981, the administration's budget considerations have dictated a reduction in funding. In response, we have been working with NASA and DOE to eliminate some costly elements of the program without impacting the major goals. The program has been slimmed down to proof of concept and essential technology which, in the long run, may serve the same purpose at considerably lower cost.

Vehicle testing by EPA and alternate fuels testing have been eliminated. There will be only one engine designed for phase I and phase II, with ceramic improvements included as they become available. This planning has resulted in a reduction of $12 million for phase I—from $47 million down to $35 million.

Assuming a funding level of approximately $10 million per year for 1983, 1984, and 1985, the program can be completed in 1985, hopefully with a satisfactory demonstration of the goals and objectives.

Let me talk a little about the outlook. Although this must be still considered a high-risk technology program, the accomplishments to date have somewhat improved the technical outlook. In fact, the ceramics accomplishments have been so encouraging that DDA is now exploring other applications. These include production aircraft engines and industrial derivatives, advanced diesel engines, military vehicle engines, and an advanced cruise missile engine. Our preliminary design studies have also shown that a scale-up of the AGT 100 could make a superior truck engine if ceramics technology continues at the present pace.

In view of the wide range of applicability, the AGT 100 concept demonstrator then takes on added importance. It not only is a concept demonstrator for automobile technology but is a scale model demonstrator for heavy-duty versions, both military and commercial. The demonstration of ceramics technology in a real engine environment can become a valuable national resource. Completing this program on the planned schedule will contribute toward maintaining this country's position of international leadership.

In conclusion, Mr. Chairman, for a proper assessment of the AGT 100 program, we must continually examine the goals and objectives in the light of competing technology. At this juncture, we have reexamined the program goals and find them still meaningful. We believe a demonstration of a gas turbine that meets the AGT 100 goals will require the automotive industry to seriously evaluate applications for automobiles as well as larger versions for heavy-duty trucks. If the program is successful, the gas turbine will play an important role in our Nation's future transportation system.

Mr. Chairman, that concludes my prepared remarks. Thank you for your attention, and I will now respond to any questions you or the subcommittee may have.

Mr. **Glickman**. Thank you, Mr. Barrett.

Mr. Dunn, do you have any questions?

Mr. **Dunn**. Mr. Barrett, on page 3 you talk about the progress made in material strength, quality, and nondestructive inspection techniques. I am not familiar with nondestructive inspection techniques. Can you explain to me what that means?

Mr. **Barrett**. Well, obviously, we must inspect all parts that we make, whether they be metal or ceramic, to determine if they are good quality, if they have flaws that will impair their utilization, and so forth.

There are several ways to do that, one of which is to sample the parts by cutting them up, which is obviously a destructive technique. Other methods such as X-rays and ultrasonics are called nondestructive inspection techniques by which we can inspect each part.

One of the most difficult parts of this program is to develop nondestructive inspection techniques for the ceramics, to know when we have good parts, even after we have developed ways of making them. Obviously, what we would like is to get a high yield of good parts from the production process.

Mr. **Dunn**. I guess you are saying to me, then, that these inspection techniques for testing ceramics have to be different than for metal. X-rays, you are saying, do not work?

Mr. **Barrett**. Yes; for one thing, we have to develop an understanding of the size of the flaw that would be destructive as compared to what it was in a metal. We have to be able to use methods that do not necessarily exhibit the total structure of the material in a ceramic as well as it did in a metal. There are new techniques being used and developed in this program.

Mr. **Dunn**. Dropping it off the table would be an example of a destructive technique?

Mr. **Barrett**. Yes.

Mr. **Dunn**. The same question I asked of the Ford and Garrett people, looking at this $100 billion deficit, the whole budget that we are talking about, and programs that have been proposed to be zeroed out by the administration, we who happen to believe in any given program are going to have a very tough fight getting those programs back in, in light of the fact that, even with them out there, we still have a $100 billion deficit.

I think it would make our case much easier to do if we could see a commitment of some percentage, even though I understand it is basic R. & D., and even though I understand that it is long range and that there are other obligations out there, but if you could supply me with some sort of willingness in terms of either percentage or dollars amounts, as I said to the Ford and Garrett people, that if our committee funds *x*, you would be willing to kick in *x* for this year, I think it would make our case more viable, and if you would supply me that information, I would appreciate it.

Mr. **BARRETT**. Well, as you know——

Mr. **DUNN**. I am not asking for it now.

Mr. **BARRETT**. I see.

Mr. **DUNN**. You can take it back to your people and discuss it and come up with some sort of proposition that you feel would be workable. I think that would make our case better.

I thank you.

Mr. **GLICKMAN**. You indicated that you thought that a minimum level of funding would be $10 million a year, I think. Wasn't that in your statement?

Mr. **BARRETT**. Yes.

Mr. **GLICKMAN**. Now, you are talking specifically about Detroit Diesel Allison, that $10 million is for your program?

Mr. **BARRETT**. Yes, sir.

Mr. **GLICKMAN**. I had the impression that DOE was only going to keep one of the two competing engine programs alive, and yet they have managed to keep both of them alive. Have you been required to put up any more money in the interim, in the last 6 months or 1 year, in order to do that?

Mr. **BARRETT**. No; as you know, this program was originally bid and contracted for as cost-share program. Our share of the total program was to be $5 million if it went to completion.

We have been living up to our share of the program, and the way we have kept the program going at the reduced funding level was to eliminate some of the things that we felt possibly were nice to have but were not necessarily essentials to proving the program out.

That we have done, and as I have mentioned, we have taken $12 million out of phase I, a good deal of which came out last year, so that our current level of funding in this program was in the vicinity of about $7 million.

In addition to that, we do support other efforts such as we have, out of our independent research funding, been supporting the GTE development to the point where they could prove whether they have a good process, and that has continued through this past year.

Now, when I mentioned $10 million, I mentioned the level of funding that was originally planned to complete this program, recognizing that there was an intent in the 1983 fiscal year to converge to one contractor. We still think that, if the Government went along with that plan, if the DOE and NASA went along with that plan, there is reasonable assurance that a good decision could be made then on the basis of demonstrated performance.

Mr. **GLICKMAN**. We thank you very much.

Go ahead, Mr. Dunn.

Mr. DUNN. Not on this subject, but last summer, when the committee visited the GM tech center, they were working on a coal-fired engine. Do you have any information on how they are doing on that right today?

Mr. BARRETT. I have no detailed information on that except that I am aware, and I think you are, that a gas turbine was run on coal. Gas turbines for years have demonstrated the capability of being able to run on almost any kind of fuel that can generate heat.

I really believe that is the reason we eliminated, in our reduced funding, the plan to demonstrate alternate fuels. Because we think that there is no question that if a gas turbine is demonstrated as viable, it will be capable of running on alternate fuels.

Mr. DUNN. If I could have an update on that coal engine, too, I would like to see some of the latest figures.

Mr. BARRETT. I will see if I can arrange for that.

Mr. DUNN. Thank you.

Mr. BARRETT. Thank you.

Mr. GLICKMAN. Before you leave, I want to ask you, how would it affect your program if NASA would withdraw from management of the program as has been proposed?

Mr. BARRETT. I think it would be unfortunate if NASA withdrew because of the background and experience they have brought to the general management of this program. They have worked very well with DOE, and we have been able to work well with both of these Government agencies in carrying out this program with DOE as the program manager and NASA as the project director.

If, on the other hand, there was a decision made that NASA withdraw, we could work directly with the DOE, as we do with many other agencies on other programs. It would probably not add to the strength of the program, but I think we could carry on that way.

Mr. GLICKMAN. All right. Thank you very much, Mr. Barrett.

Next, we have Dr. Gene Mannella, vice president and general manager of Mechanical Technology, Inc., the Stirling engine systems division. We appreciate your being here. As I have indicated to the other witnesses, your entire statement will appear in the record, so you may deem it appropriate to summarize or not, as you wish.

STATEMENTS OF DR. GENE G. MANNELLA, VICE PRESIDENT AND GENERAL MANAGER, STIRLING ENGINE SYSTEMS DIVISION, MECHANICAL TECHNOLOGY, INC.; ACCOMPANIED BY NOEL P. NIGHTINGALE, AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM MANAGER

Dr. MANNELLA. Thank you, Mr. Chairman.

I do have some summary material that I would like to use in lieu of vu-graphs.

I would also like to take this opportunity to introduce my colleague, Mr. Noel Nightingale, who is the program manager for the automotive Stirling engine program at MTI. Much of the success that I am going to describe today is due to his efforts.

Just taking a look at the overview charts [fig. 1], the first thing that I would like to mention, Mr. Chairman, is the effect of the budget reductions that we have had in 1981 and 1982, because I think it bears on several of the issues that you have discussed with some of the other contractors, and it bears upon the original timeframe for title III.

The design of the Mod II engine has been canceled. You recall that the program was a two-engine program. Mod I was a performance engine; Mod II was a manufacturing oriented, cost reduction engine. The Mod II design work would have started, in the original program, this year.

We have had to cut back component development activities in view of about a 40-percent reduction in the budget this year and some reduction in 1981.

We have reduced the number of engines, the hardware that we have to work with.

All of the efforts relating to public demonstration of Stirling engines and vehicles have been canceled.

Work related to vehicle integration at AM General was rather significantly reduced. As a matter of fact, under the ground rules, for a technology proof-of-concept program, it would have been entirely eliminated. However, keep in mind that the Stirling engine program was put into place approximately 1 year before the gas turbine programs, and we are somewhat farther along. Inasmuch as we had a vehicle that had been about 85-percent modified, we will be installing a Mod I engine in this vehicle at AM General this month.

With that as a background, I would like to talk about the major program accomplishments which are shown on the next page [fig. 2].

The major fiscal year 1981 milestone, which is really the major milestone of the program to date, that is, testing and fully characterizing the first Mod I engine was completed 1 month ahead of schedule; that is, the end of August 1981.

We have manufactured, assembled and tested three Mod I engines. One is on test at United Stirling in Malmo; one is on test at MTI in Latham, N.Y., and one is at AM General being installed in a vehicle.

We have accumulated, primarily on the first Mod I engine, 500 test hours by mid-February. The transfer of technology has been increased very substantially during the past year. We have Mod I testing initiated in the United States. We have more than 30 vendors established in the United States supplying components for the Mod I engine and seven major development rigs operational at MTI during the past year.

We have run a multifuel test. Five different fuels which are listed in my statement were run in a Stirling engine without any change in hardware, without any noticeable degradation in performance, and well within the emission indices that were established for the program.

Turning briefly, I have a few charts which I would just like to comment on. The first one [fig. 3] shows the data from the first Mod I engine on power output. You will see that the data is coming in somewhat higher than the projections that we made using the computer codes that were used in the design of the engine. I would like to stress that this is the first data off the first engine, and we have every reason to believe that this is going to improve as the engine development program moves along.

The next chart [fig. 4] shows the engine efficiency. Again, the dashed lines are the actual engine data. Looking particularly at the top lines, you will see that the engine efficiency comes in just slightly below the computer prediction; it is about 37.7 percent. More interestingly, it is down around 1,200 or 1,400 r.p.m., which is where you want to design the automotive engine as opposed to the stationary engine that we used as our baseline.

Again, for automotive application, on the next chart, I would like to just talk briefly about the brake-specific fuel consumption, that is, the pounds of fuel per horsepower hour, and compare it to what we think are the best data that we can get on today's engines [fig. 5].

The solid line is a very good internal combustion engine, an Otto cycle engine. The next dashed line is a turbocharged diesel engine, an engine that is touted as one of the leaders in fuel economy.

The Mod I data is the bottom dashed line, and you will see that the specific fuel consumption actually goes below 0.4, which is a barrier or a magic number in terms of fuel consumption. More importantly, it is a very flat curve, which means that you can operate over quite a power range with about the same optimal fuel consumption characteristics. This means that the performance in the automobile, in the various driving cycles, looks very, very promising with an engine of this type.

The next graph is the actual histogram of the engine test hours for the first engine, starting back in January 1981 when it was tested; first, as a basic engine and then as an engine system [fig. 6]. The point I would like to make is that the accumulation of hours has been fairly constant, with the exception of the July timeframe, which is the vacation period, when the test cells were shut down. This means that we have encountered very little in the way of mechanical problems with this engine. In other words, we did not have a big spike of engine testing and then a flat period of 4 weeks or 6 weeks while we tried to solve problems. The engine is very promising in the early phases of testing.

The next table is a glimpse at what we think some of the pertinent numbers are related to the projected vehicle mileage. There is a typo on this chart in the first line [fig. 7]. The first mileage figure should be for the Mod I. The second set of figures are for the IC engine.

But using the data from the Mod I, we see in a 1982 Spirit, this engine—again, a performance engine, not an optimized engine—is 12-percent better than the existing IC engine. The reference engine that we have been designing over the past couple of years, which would have been the preliminary design for the Mod II had we continued into the Mod II design, shows that in a 3,000-pound 1982 X-body car, we can expect a 52-percent improvement in miles per gallon; 41.1 miles per gallon combined cycle.

Taking that engine and simply downsizing it without trying to optimize the performance, in a 2,250-pound 1982 subcompact, shows that we can still expect a 40-percent improvement in miles per gallon in that class of vehicle.

Turning briefly now to the proposed fiscal year 1983 program, we propose to continue the development of the Mod I, upgrading it, paying particular attention to manufacturing cost, small-vehicle packagability, which we think is a very important area, and increasing work with our vendors on manufacturing techniques [fig. 8].

Also, in keeping with some of the comments that you heard earlier this morning, you cannot do engine development independent of the environment in which it has to operate. You have to look at the transient capabilities as they apply to an automotive application: acceleration, cold weather operation, emissions, and various operating conditions.

And, finally, we are going to make a very special effort to bring the data that we are accumulating and developing to the automotive industry and to try to get from them both advice and guidance on how to improve the development of the engine, goals with which we can strive to meet some of their criteria, and inputs on manufacturability and cost reduction.

In summary, I would like to point out, Mr. Chairman, that we think that the ASE program is a very successful program [fig. 9]. It is probably going to exceed its technical goals. It is on schedule; it is within cost. We think it is the type of program that the Federal Government should support in order to address major national needs.

As I pointed out in the written testimony, Stirling engine technology is actually receiving increased attention and support by foreign governments, notably in Japan and Germany. This may lead to a broad array of energy-efficient products not only in the automotive area but in many of the other applications that, again, you have already heard about this morning, where advanced heat engines of this type could be utilized in very attractive consumer products.

We do not see any evidence of any increased interest in supporting a program of this type on the part of the private industry. We are looking now to the automotive industry, buttressed by the actual data that we have on performing engines, to work with us, to give us inputs, to come out and develop with us the goals that we have to strive toward in order to make this a viable commercial entity.

Finally, we think that the original goals of title III are still valid and in the Nation's best interest. We do not think that the timeframe of 1984 is realizable because of the budget reductions that have occurred in the past several years. But we do think that the development of a viable alternative powerplant, with all of the characteristics that made this one of the two choices in the JPL report, can be met within the original dollar scope of the program but delayed by 1 to 2 years, depending on when those goals would be reaffirmed.

With that, Mr. Chairman, I would be happy to answer any questions that you might have.

[Figs. 1-9 of Dr. Mannella's statement follow:]

IMPACT OF FY '82 BUDGET REDUCTION

- THE DESIGN OF THE MOD II ENGINE WAS CANCELLED (MAKING IT IMPOSSIBLE TO MEET THE TIME FRAME ESTABLISHED FOR TITLE III, PL 95-238).
- COMPONENT DEVELOPMENT ACTIVITIES WERE SIGNIFICANTLY REDUCED WITH ATTENDANT INCREASES IN TECHNICAL RISK.
- THE NUMBER OF ENGINES WITHIN THE PROGRAM WAS REDUCED 50% — FROM EIGHT TO FOUR.
- ALL EFFORTS ON PUBLIC DEMONSTRATION OF STIRLING ENGINES AND RELATED EDUCATIONAL ACTIVITIES WERE CANCELLED.
- WORK RELATED TO VEHICLE INTEGRATION AT AM GENERAL WAS SIGNIFICANTLY REDUCED, CURTAILING THE MOST PROMISING ROUTE TO EXPOSURE OF MOD I RESULTS TO THE DOMESTIC AUTOMOTIVE INDUSTRY IN DETROIT.

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FIGURE 1

MAJOR ASE PROGRAM ACCOMPLISHMENTS

- THE MAJOR PROGRAM MILESTONE OF TESTING AND FULLY CHARACTERIZING THE FIRST MOD I ENGINE SYSTEM BY SEPTEMBER 30, 1981 WAS COMPLETED ONE MONTH AHEAD OF SCHEDULE.
- THREE MOD I ENGINES WERE MANUFACTURED, ASSEMBLED, AND TESTED.
- APPROXIMATELY 500 TEST HOURS WERE ACCUMULATED ON THE MOD I ENGINE BY MID-FEBRUARY, 1982.
- TRANSFER OF STIRLING ENGINE TECHNOLOGY WAS INCREASED MARKEDLY; VIZ.,
  - MOD I ENGINE TESTING WAS SUCCESSFULLY INITIATED IN THE U.S.A.
  - MORE THAN THIRTY VENDORS WERE ESTABLISHED IN THE U.S.A. FOR THE MANUFACTURE OF STIRLING ENGINE COMPONENTS
  - SEVEN MAJOR DEVELOPMENT RIGS WERE MADE OPERATIONAL AT MTI DURING THE PAST TWELVE MONTHS.
- A STIRLING ENGINE WAS SUCCESSFULLY TESTED WITH FIVE DIFFERENT FUELS WITHOUT ANY CHANGE IN ENGINE HARDWARE. THE ENGINE POWER AND PERFORMANCE DID NOT CHANGE APPRECIABLY, AND NO CHANGE WAS MEASURED IN EMISSIONS LEVEL AS COMPARED TO THE BASE FUEL OF UNLEADED GASOLINE.

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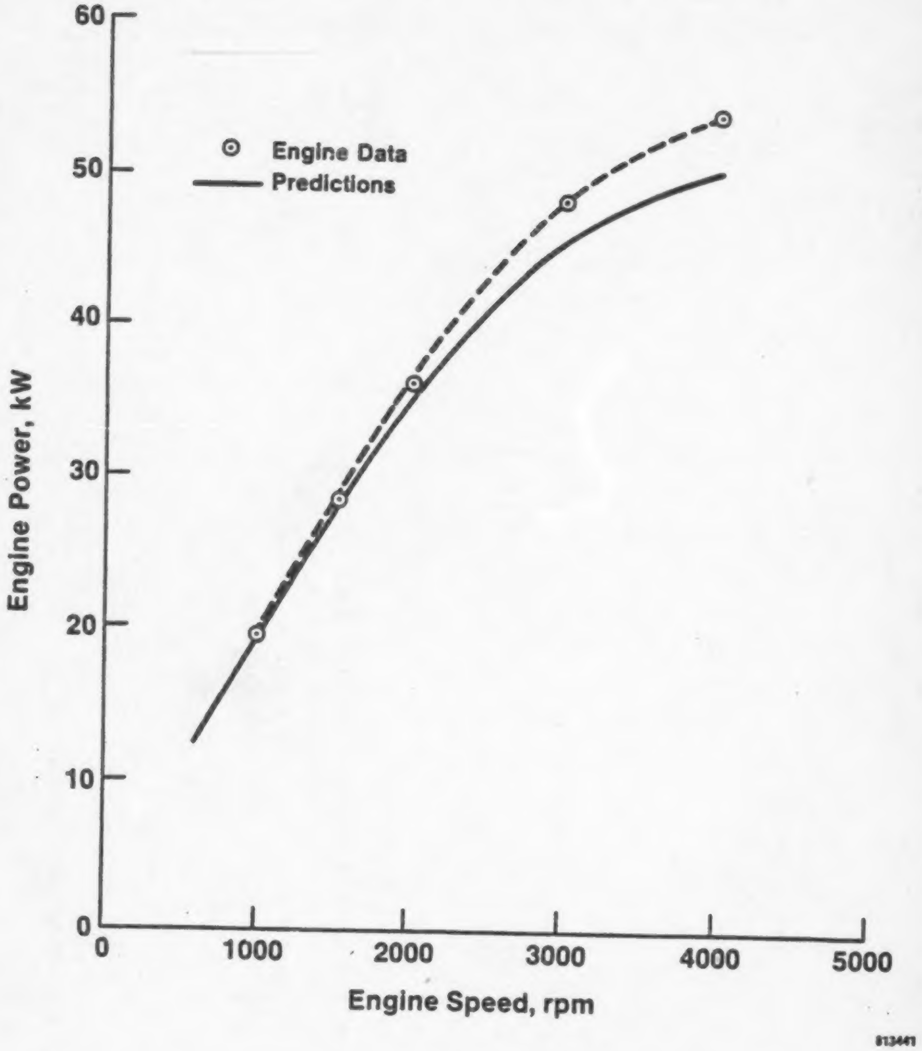
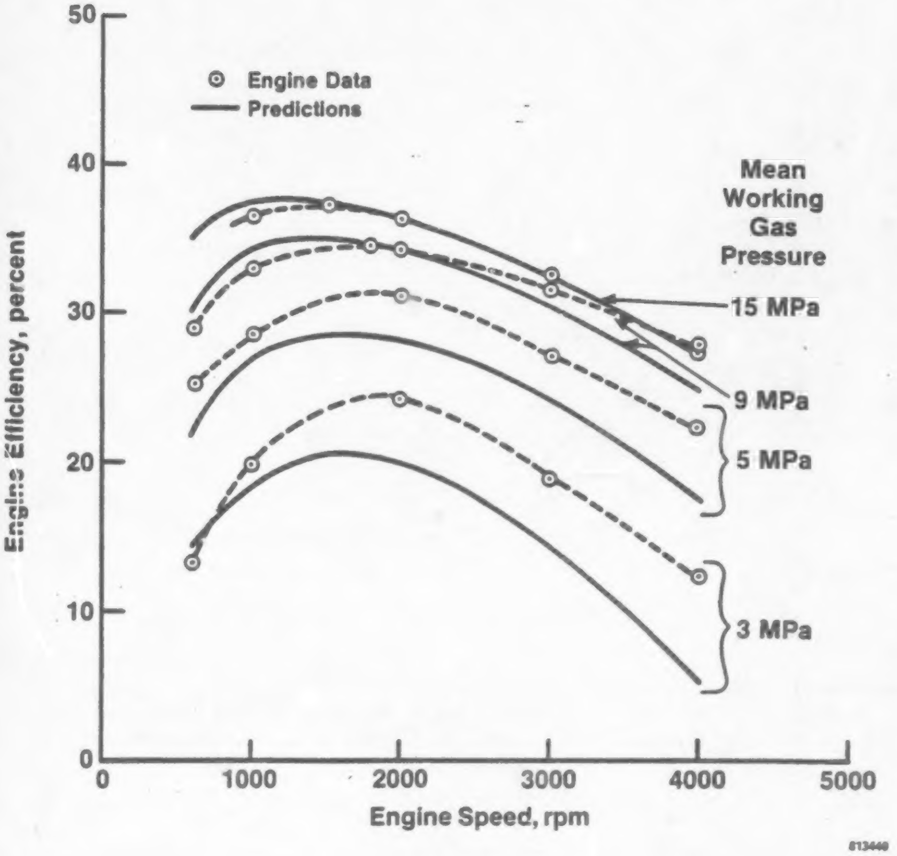
FIGURE 2



Mod I Stirling Engine System Maximum Power Characteristics

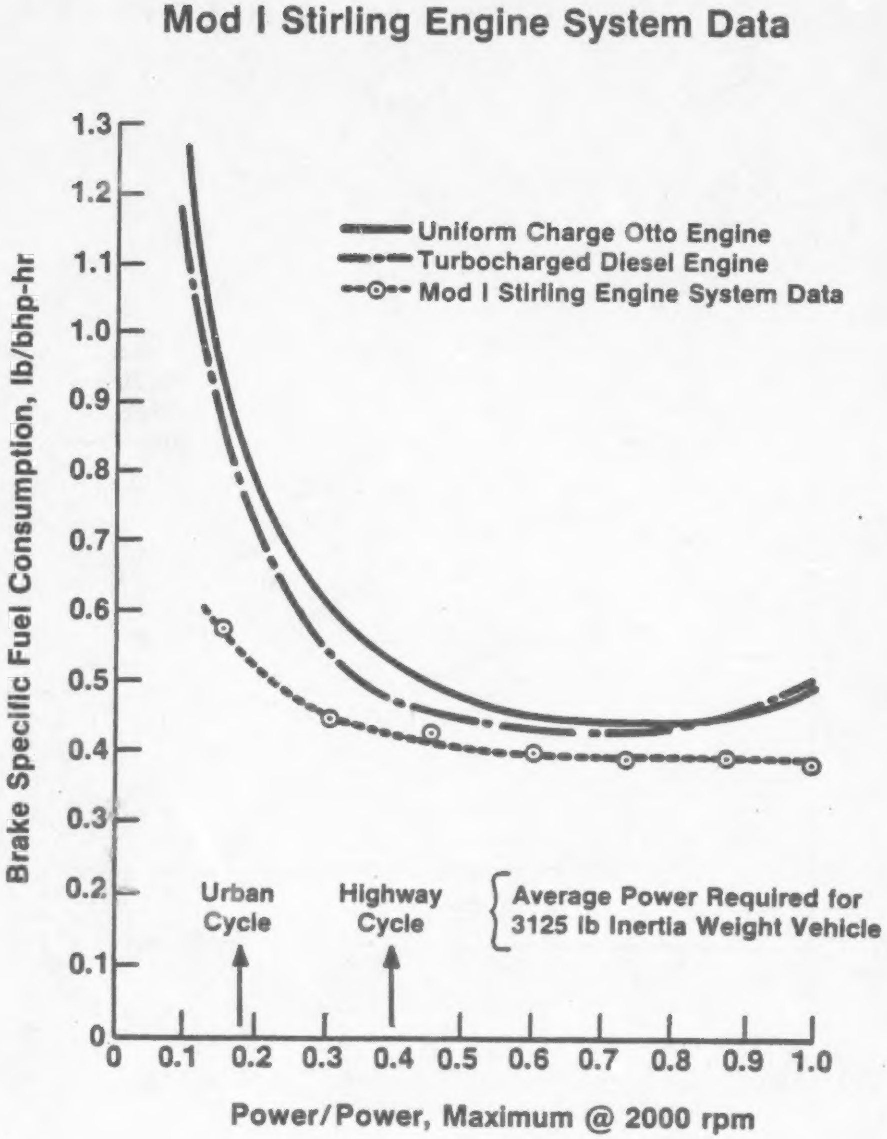
FIGURE 3

Mod I Stirling Engine System Data



Mod I Stirling Engine System Efficiency Characteristics

FIGURE 4



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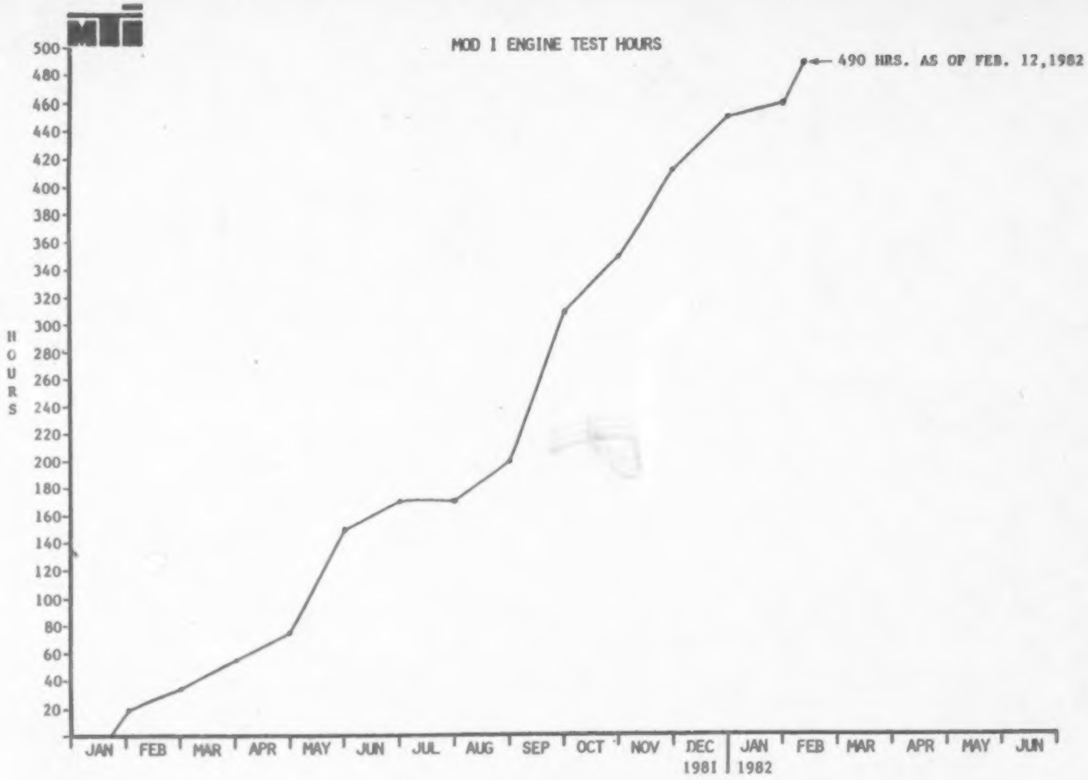
Engine Fuel Consumption Comparisons

FIGURE 5



Chronological Accumulation of Mod I Test Hours

FIGURE 6

STIRLING ENGINE VEHICLE MILEAGE COMPARISON

	Vehicle	Inertia Weight Class	Mileage		
			Urban	Hwy	Combined
IC Engine	1982 AMC Spirit	3000 lb	23	38	28
			23	29	25
			Improvement		12%
Reference Engine (Mod II)	1982 X-Body	3000 lb	33.3	57.4	41.1
I.C. Engine			23	33	27
			Improvement		52%
Down-Sized Reference Engine	1982 Subcompact	2250 lb	40.3	77.5	51.4
			32.7	43.6	36.8
			Improvement		40%

NOTE: All comparisons made for identical acceleration times; unleaded gasoline.

FIGURE 7

PROPOSED FY '83 PROGRAM

- THROUGH A COMPREHENSIVE ENGINE TEST PROGRAM, THE STIRLING ENGINE WILL BE PROVEN IN REGARD TO RELIABILITY AND DURABILITY REQUIREMENTS OF THE AUTOMOTIVE APPLICATION.
- MARKED IMPROVEMENTS WILL BE MADE TO THE STIRLING ENGINE SYSTEM AS IT APPLIES TO:
  - PERFORMANCE AND FUEL ECONOMY
  - MANUFACTURING COST
  - SMALL-VEHICLE PACKAGEABILITY
  - MANUFACTURING TECHNIQUES.
- PROOF OF ITS TRANSIENT CAPABILITIES (AS APPLIED TO THE AUTOMOTIVE APPLICATION) IN ACCELERATION, COLD-WEATHER OPERATION, AND EMISSIONS WILL BE ESTABLISHED, AND ALTERNATIVE FUEL EVALUATIONS WILL CONTINUE.
- THIS PROOF-OF-CONCEPT PROGRAM WILL BE MADE POSSIBLE IN A VERY COST-EFFECTIVE MANNER, SINCE EXISTING ENGINE HARDWARE WILL BE USED IN A MAJORITY OF CASES.
- FINAL DEMONSTRATION OF THE TRANSFER OF STIRLING ENGINE TECHNOLOGY WILL BE ACCOMPLISHED THROUGH DESIGN, MANUFACTURE, ASSEMBLY, TEST AND DEVELOPMENT.

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FIGURE 8

SUMMARY

1. THE ASE PROGRAM IS A SUCCESSFUL EXAMPLE OF THE TYPE OF PROGRAM THAT SHOULD BE SUPPORTED BY THE FEDERAL GOVERNMENT TO ADDRESS MAJOR NATIONAL NEEDS. THE ONGOING PROGRAM WILL PROBABLY EXCEED THE TECHNICAL GOALS ESTABLISHED FOR THE MOD I ENGINE, IS ON SCHEDULE AND WITHIN COST.

2. STIRLING ENGINE TECHNOLOGY IS RECEIVING INCREASED ATTENTION AND SUPPORT BY FOREIGN GOVERNMENTS, WHICH MAY LEAD TO A BROAD ARRAY OF ENERGY-EFFICIENT PRODUCTS THAT CAUSE DOMESTIC ECONOMIC DISLOCATION.

3. THERE IS NO EVIDENCE THAT U.S. INDUSTRY IS IN A POSITION TO PURSUE THIS TECHNOLOGY WITHOUT SUBSTANTIAL GOVERNMENT SUPPORT. WE ASK THE AUTOMOTIVE INDUSTRY TO GET INVOLVED TO THE EXTENT OF SUGGESTING SPECIFIC GOALS TO DOE AND NASA FOR THE FY '83 PROGRAM.

4. THE ORIGINAL GOALS OF TITLE III OF PL 95-238 ARE STILL VALID AND IN THE PUBLIC'S INTEREST. A SECOND-GENERATION COMMERCIALIZABLE STIRLING ENGINE CAN BE REALIZED WITHIN THE FUNDING ESTIMATES FOR THE ORIGINAL PROGRAM, ALTHOUGH THE TIME FRAME WILL HAVE TO BE ADJUSTED BECAUSE OF THE REDUCED EFFORT IN FY '81 and '82.

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MTI-17778

FIGURE 9

Mr. GLICKMAN. Thank you, Gene.

If the program is terminated, as the administration has proposed, at the end of fiscal 1982, what milestone will you reach, and would industry be likely to continue on its own?

Dr. MANNELLA. If the program is terminated at the end of 1982, I think we will have a semideveloped Mod I. That is, we will have met the major milestone of characterizing a Mod I. We will be 40 percent into the development and the upgrading of it.

I do not think that industry would be likely to pick that up because I think it would still require a fair amount of technology development in order to bring the risk down to the level that they would be willing to accept.

Mr. GLICKMAN. How many dollars do you think are needed for fiscal 1983, 1984, 1985, or however far you think the program needs to continue, at a minimal level of Federal dollars?

Dr. MANNELLA. What we are suggesting in the written testimony was a program level of $12 million in 1983, which I think would give us an aggressive, robust engine development program.

Beyond that, it gets difficult to say because it depends on whether or not it is decided to pursue the Mod II, that is, to go into the second generation, manufacturing-oriented, cost-reduced engine.

I still think that a program level of about $12 million a year would be required to fulfill the original goals of title III. If we were to start on that now, we could probably do it by the fall of 1985; that is, slipping the title III goals by 1 year. If that is not resolved until into 1983, it probably means that it would be 1986 before the title III goals were fully met.

Mr. GLICKMAN. You may have talked about this in your written testimony. Are any essential elements being left out of the current proof-of-concept program such as dynamometer testing of the upgraded Mod I engine? Is there anything in particular that is being left out?

Dr. MANNELLA. Well, what we have done—and, again, it is consistent with what you have heard this morning—is we have worked with NASA and DOE to protect the essential ingredients of the program, which is the hardcore engine development. We have reduced component work. We have reduced the number of engines. We have all communally accepted higher technical risk in not having the component development and testing.

The one thing which has clearly been eliminated is all attempts at commercialization. All of the efforts within the program specifically directed to commercialization have been eliminated as the program has been converted to a proof-of-concept program.

Mr. GLICKMAN. And the $12 million funding figure would not reinstate that commercialization?

Dr. MANNELLA. That is correct. The $12 million funding figure would be an engine development program embracing Mod II by either 1985 or 1986, depending upon when Mod II was given the OK.

Mr. GLICKMAN. You talked a little bit about the state of the art in other countries. Do you have any idea how much other countries are spending on their Stirling programs?

Dr. MANNELLA. It is very difficult to tell. There was an article, of which I included a translation in my testimony, that appeared in a

Japanese magazine several months ago which talks about a MTI-sponsored program of some $40 or $50 million.

However, we know that there has been a substantial amount of work going on in Japan well prior to this program, and I included a list of companies that we knew in 1979 were involved in Stirling engine technology.

I think that we are just seeing the tip of the iceberg. I think that the announcement of the MTI program is merely a visible acknowledgment or admission of a program that has been going on for some years.

I do not have any factual data; I just simply have a visceral feeling that the total program is two to three times what MTI currently announced.

Mr. GLICKMAN. What about elsewhere, besides Japan?

Dr. MANNELLA. Well, in Germany, it is rather hard to tell. We do know that Daimler is very actively looking at Stirling engines for a variety of automotive and transportation applications.

There have been programs financed by the German Government at MAN for a number of years, apparently for military applications about which we have been able to find out very little, if anything.

I might suggest, if I may, Mr. Chairman, that you address that question to NASA at the hearing tomorrow. They may have much better access to this type of information than we are able to get.

Mr. GLICKMAN. I have one final question for you. There are critics who argue that the Stirling's weight-to-horsepower ratio is too high to be competitive, that expensive alloys are needed for its manufacture, and ceramics are not a viable substitute because of the high pressures, and that no repair or maintenance infrastructure exists. How do you respond to these?

Dr. MANNELLA. Well, I would like to take those in order if I can recollect them. As to the weight-to-horsepower ratio, we have already shown that we have cut it in half from the stationary engine to the Mod I. The original program was designed to cut it in half again in going to the Mod II. To say that we will not get there is to say that we will make zero progress in the future, which certainly our performance over the last several years has belied.

The ceramics question is very, very interesting. In a program that we funded with MTI money, we looked at a number of engine alternatives, and we specifically looked at a high-temperature engine. I believe we looked as high as 1,100° C.

What we found out is that with the Stirling cycle in the power range that we are talking about, and when you already see 37.7 percent, you really do not gain an awful lot in efficiency by raising the temperature significantly. So you do not need ceramics for high performance.

We are, however, very interested in the ceramics program as a means of cost reduction. If the ceramics work that is going on can be translated to the Stirling program, in the hot parts of the engine, then we would hope to reap the same benefits in cost reduction that you saw on the graph that was presented this morning by the Garrett Corp.

So we are interested in it from a cost and manufacturing standpoint, but not really from a performance standpoint, because we do not really see the gains there.

In terms of the infrastructure, to a certain extent, that is true. However, I would refer you to the cross section of the Stirling engine that is in my testimony. Except for the hot end of the engine, it looks like pretty conventional hardware. You are talking pistons, and crankcase, and gears, and things of this sort.

There certainly is some difference in the hot end of the engine, but the engine also has some very strong potential for very low maintenance because of the lack of a requirement for spark plugs, and no valves, and things of this sort. We do not think that infrastructure will be a big obstacle to overcome in commercializing these engines.

Mr. GLICKMAN. Thank you.

Mr. Dunn?

Mr. DUNN. The other two programs that we were looking at involved Ford Motor and General Motors, members of the "Big Three." You and I have chatted in the past about the difficulty of getting the "Big Three" to agree with what you are doing, be interested in what you are doing. One of those basic problems was that the "Big Three" have been hestitant in actually giving you goals, I believe we talked about, in establishment.

In the light of the success you have had, particularly in the last 60 days, have you made any progress, doctor, toward their saying to you exactly what it is they need?

Dr. MANNELLA. We have not really quite taken that initiative yet, Mr. Dunn. There are several activities going on at NASA that we think will be very useful precursors to our initiative, plus the fact that we would like to get data on subsequent engines to show engine-to-engine consistency.

NASA has a study called STAR, I believe, Stirling technology applications review, which we think will be very useful in putting the application of Stirling technology into a perspective for the U.S. market.

In addition, we do know that NASA is meeting with various companies and updating their top management on the progress on the Stirling engine.

We would like to follow that up at a somewhat later date, in a few months, armed with data that is just as meaningful from our second and third engines and perhaps some from a vehicle application and then begin that dialog with the automotive industry.

Mr. DUNN. I would think that both you and I would agree that would be critical to the success of the program——

Dr. MANNELLA. Absolutely.

Mr. DUNN [continuing]. To very deeply involve the "Big Three" in what you are doing and get them to believe in it. I see that is a very large stumbling block yet to be conquered.

Dr. MANNELLA. We are very interested in pushing that because I think that to merely develop the technology and not have it utilized is a real form of disappointment to a group of technology people. We have some very dedicated people working on this program, and they want to see it commercialized. My company wants to see it commercialized. We hope to be very aggressive in this arena over the next year or so.

Mr. DUNN. I thank you.

Mr. GLICKMAN. Thank you, Gene, very much for your testimony.

We will meet tomorrow at 10 a.m. to hear from Mr. Joe Tribble, Assistant Secretary of the Department of Energy, as well as from Jack Kerrebrock of NASA.

The hearing will be adjourned until tomorrow.

Dr. **Mannella**. Thank you, Mr. Chairman.

[Whereupon, at 11:31 a.m., the subcommittee recessed, to reconvene on Wednesday, March 3, 1982, at 10 a.m.]

[The prepared statement of Dr. Mannella follows:]

Testimony
on
DOE Transportation Program
before
Subcommittee on Transportation, Aviation and Materials
Committee on Science and Technology
House of Representatives

March 2, 1982

Prepared by:

Dr. Gene G. Mannella

Mechanical Technology incorporated

Biography of Gene G. Mannella

Mechanical Technology Incorporated
Latham, New York

Dr. Gene G. Mannella is Vice President and General Manager of the Stirling Engine Systems Division at Mechanical Technology Incorporated in Latham, New York, a high-technology R&D and manufacturing concern. His responsibilities include research, development, and technology transfer of Stirling engines and systems utilizing this advanced heat engine. Dr. Mannella was Senior Vice President of the Institute of Gas Technology from 1977 to 1979. Prior to that, Dr. Mannella held a series of Government positions in ERDA, DOT, and NASA, where he was responsible for Federal programs in energy conservation, vehicle safety, and aerospace technology, respectively. He has authored numerous technical papers, served as chairman of two International Conferences on Experimental Safety Vehicles under NATO/CCMS sponsorship, and was head of the U.S. Section on Automotive Transport of the Joint US-USSR Technical Exchange on Transportation. Dr. Mannella is a recipient of the NASA Apollo Achievement Award, the DOT Award and Medal for Meritorious Achievement, and the ERDA Award for Outstanding Leadership. He received a B.S. Ch.E. (with honors) from Case Institute of Technology in 1953 and a Ph.D. from Rensselaer Polytechnic Institute in 1956.

Testimony of Dr. Gene G. Mannella
Mechanical Technology Inc.
Latham, N.Y.
before
The Subcommittee of Transportation, Aviation and Materials
House of Representatives
March 2, 1982

Mr. Chairman, my name is Gene G. Mannella, and I am Vice-President and General Manager of the Stirling Engine Systems Division of Mechanical Technology Incorporated (MTI). MTI is a high-technology research, development, and manufacturing company located primarily in New York, but including wholly-owned subsidiaries in Port Huron, Michigan, and Anaheim, California. The Stirling engine development team at MTI, consisting of approximately 100 people, is engaged in the development of both kinematic and free-piston Stirling engines for a variety of potential product applications. As far as we can determine, MTI, equipped with unique test facilities, employs the largest group of Stirling engine specialists in the world. MTI formed this team in response to a national need for this advanced, energy-efficient technology, which had been almost solely under development in Europe and Japan.

Mr. Chairman, my company appreciates the opportunity of appearing before this subcommittee. My testimony today consists of a status report on the Automotive Stirling Engine (ASE) Program (funded by the Department of Energy under Title III of Public Law 95-238), a discussion of the negative impact of the Administration's FY '83 budget request, and some observations concerning the relative position of the United States, Europe, and Japan in the development of this promising technology.

In Section 302 (b) of Public Law 95-238, Congress charged the Department of Energy to initiate a program leading to the development of an advanced automobile propulsion system. Two basic engine cycles were selected for inclusion in the program: the Brayton, or gas turbine engine, and the Stirling engine. MTI is the prime contractor on the Stirling engine program.

The Stirling engine has the intrinsic capability of providing the highest efficiency and fuel economy of any engine cycle. This engine also uses continuous, external-combustion for its heat source, a feature that allows maximum latitude in fuel flexibility and minimizes emission levels. Figure 1 shows a cross section of the automotive Stirling engine. The lower part of the engine is similar to an internal-combustion engine; however, the upper part, or hot end of the engine, is rather unique. It is in this area where the major challenge of developing long life, low maintenance, and reasonable cost solutions exists.

The Stirling Engine Program Team consists of MTI as the prime contractor, United Stirling of Sweden as the principal Stirling engine technology support group, AM General as the engine system integrator, and Ricardo Engineering of England as the engine drivetrain expert. The strategy of the original program to meet the Title III objectives was to transfer the stationary Stirling engine technology of Sweden to the United States and convert it to a form applicable to the automobile. This task was to be accomplished by June, 1984. The original approach was to take the existing stationary P-40 engine and modify it in two steps to an engine that could be placed in a front-wheel-drive vehicle to achieve a minimum program goal of 30% improvement in fuel economy using unleaded gasoline. FY '81 and '82 budget reductions have altered both the size and timetable of the original program, as will be discussed in the next section.

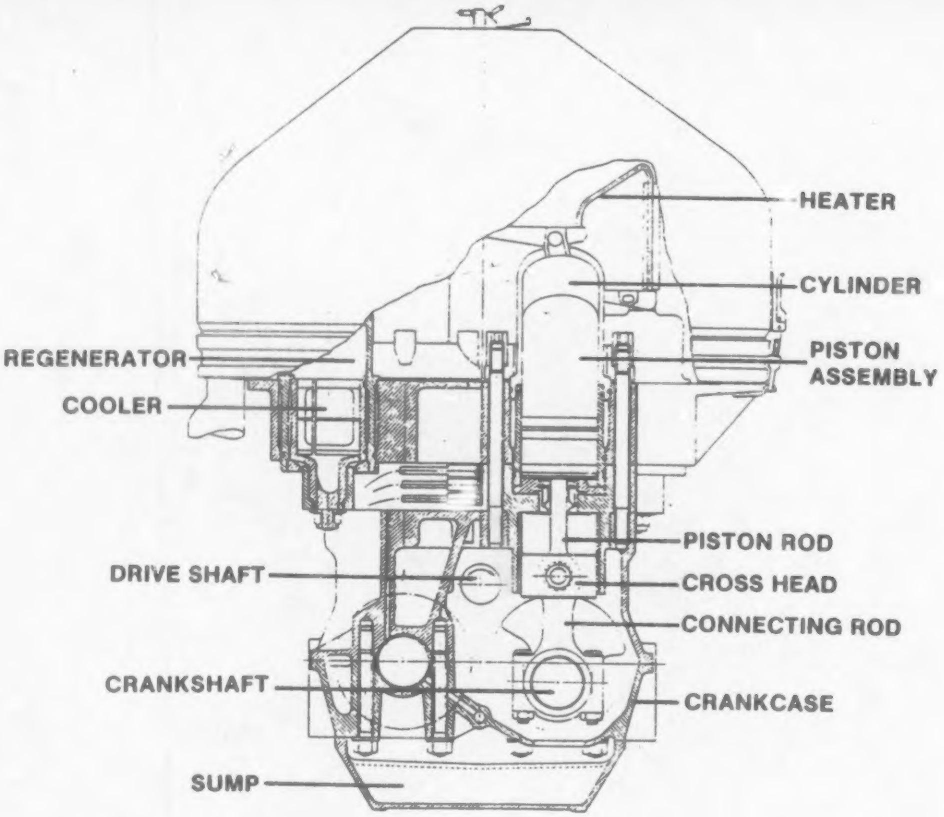
HEATER
CYLINDER
PISTON ASSEMBLY
REGENERATOR
COOLER
PISTON ROD
CROSS HEAD
DRIVE SHAFT
CONNECTING ROD
CRANKSHAFT
CRANKCASE
SUMP

Figure 1 Reference Engine System Design

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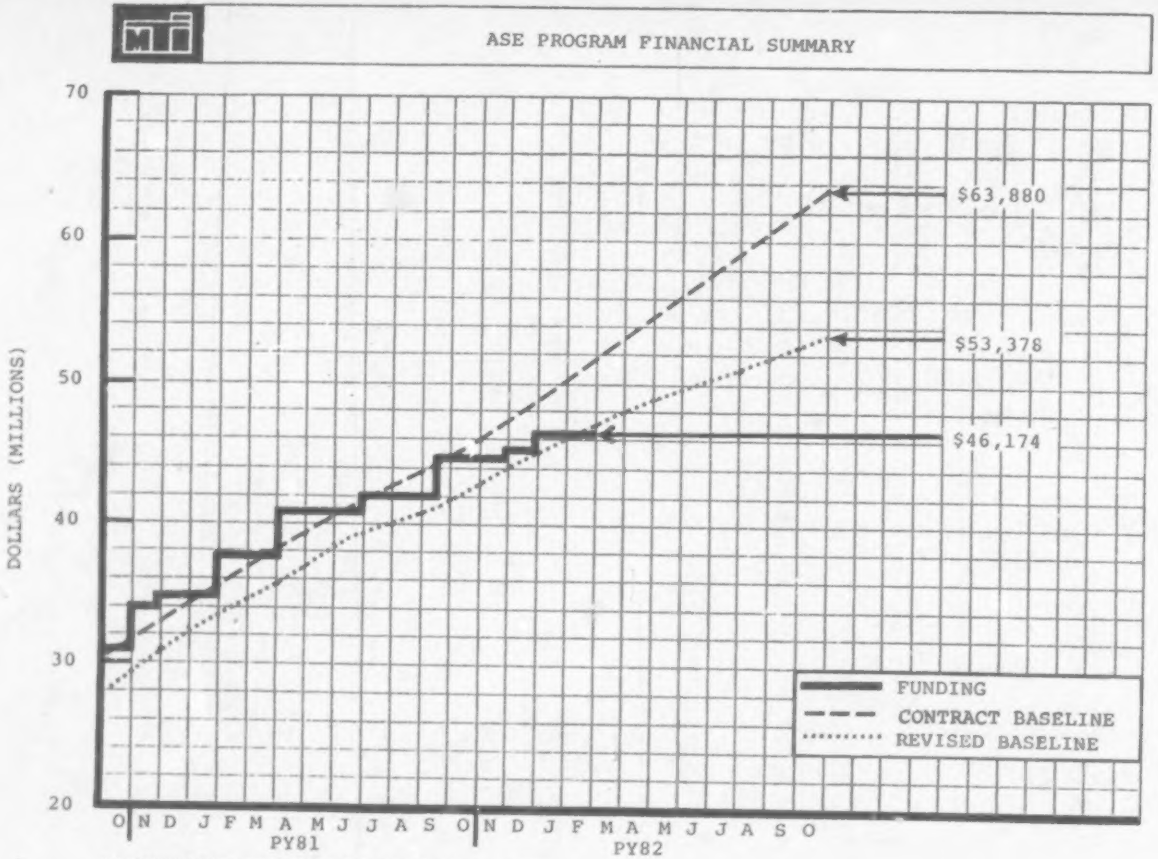
Impact of FY '82 Budget Reduction

The original, two-engine generation program called for a peak effort in FY '82 and expenditures of approximately $18M. Actual funds available from the FY '82 appropriation are $8.7M which, coupled with carry-over funds from FY '82, allow a program level of slightly more than $10M. In addition, FY '82 funding has actually been provided to the prime contractor by a series of monthly contract modifications, rather than the more usual three- or four-month allocation. The results of these budget actions are as follows:

- the design of the Mod II engine was cancelled (making it impossible to meet the time frame established for Title III, PL 95-238);
- component development activities were significantly reduced with attendant increases in technical risk;
- the number of engines within the program was reduced 50% - from eight to four;
- all efforts on public demonstration of Stirling engines and related educational activities were cancelled; and,
- work related to vehicle integration at AM General was significantly reduced, curtailing the most promising route to exposure of Mod I results to the domestic automotive industry in Detroit.

Figure 2 shows how the program spending rate was reduced from the original Title III baseline contract. During FY '81, more than three-million dollars was rescinded from the program, while in FY '82, the budget was reduced by approximately 40%. The difficulties in managing the program because of the manner in which the funding is released is also a major concern. Throughout



MECHANICAL TECHNOLOGY INCORPORATED

Figure 2

this fiscal year, funds have been released in small increments, making it very difficult to execute any foreward planning. In some cases, planning is restricted to two-week increments. Releasing funds in small increments has and will cost the Government more money in the long run, e.g., delays in hardware purchases eliminate the ability of obtaining an optimum price and delivery date.

Major ASE Program Accomplishments

In spite of budget uncertainties and funding cutbacks, major accomplishments during FY '81 and '82 include:

- The major program milestone of testing and fully characterizing the first Mod I engine system by September 30, 1981 was completed one month ahead of schedule.
- Three Mod I engines were manufactured, assembled, and tested.
- As shown chronologically in Figure 3, approximately 500 test hours were accumulated on the Mod I engine by mid-February, 1982.
- Transfer of Stirling engine technology was increased markedly; viz.
    - Mod I engine testing was successfully initiated in the U.S.A.;
    - more than thirty vendors were established in the U.S.A. for the manufacture of Stirling engine components; and,

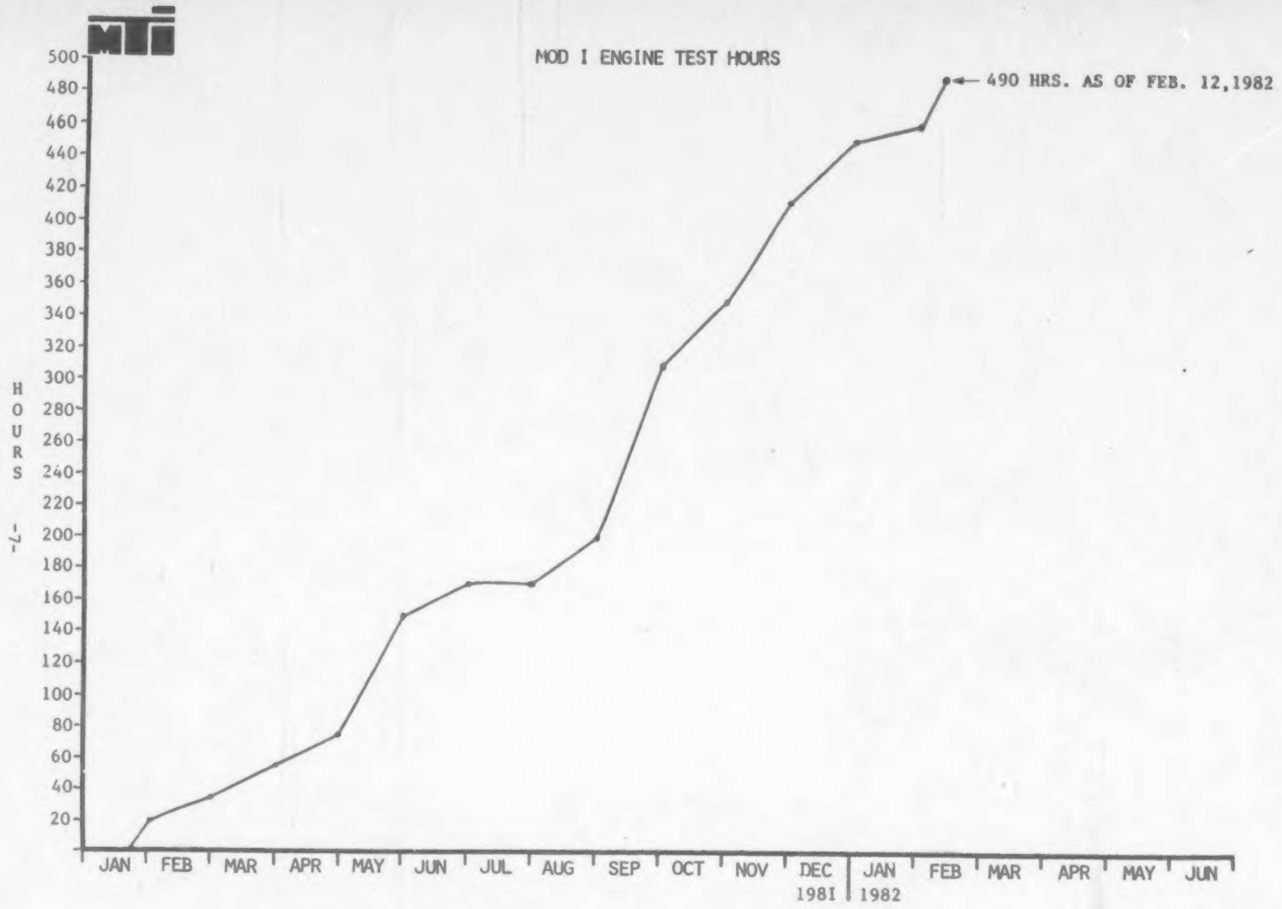


Figure 3 Chronological Accumulation of Mod I Test Hours

  - seven major development rigs were made operational at MTI during the past twelve months (these rigs are an integral part of technology transfer and future technology advancement).

- A Stirling engine was successfully tested with five different fuels without any change in engine hardware. The engine power and performance did not change appreciably, and no change was measured in emissions level as compared to the base fuel of unleaded gasoline.

Following is a presentation with detailed data supporting these accomplishments.

MOD I ENGINE DATA

Summary

Testing of the Mod I engine to date has resulted in the following progress:

- Peak Power = 53.9 kW (72.3 hp) versus 50 kW design
- Maximum Efficiency = 37.4% versus 37.7% design
- Minimum BSFC = 0.37 lb/bhp-hr
- Low fuel consumption region is seven times as large as corresponding region for diesel engines.
- Exhaust emissions are consistent with Federal emission goals:

0.4 g/mi NO_x
3.4 g/mi CO
0.41 g/mi HC

Mod I Engine Performance Power and Efficiency

Current engine data shows the following:

- Power characteristics similar to predictions, but at slightly higher levels.
- Refering to Figure 4, at lower engine speeds, power is slightly above predictions; at higher rpm's, data is 8% higher.

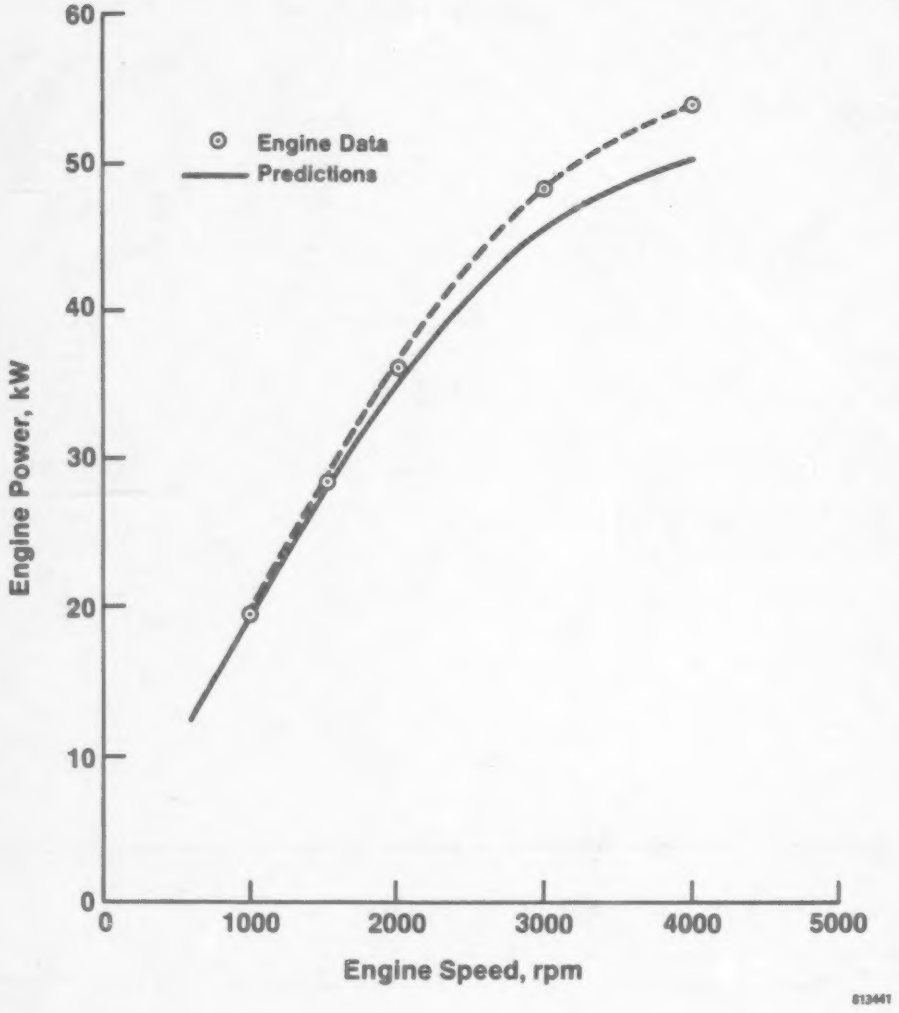


Figure 4 Mod I Stirling Engine System Maximum Power Characteristics

- referring to Figure 5, peak measured efficiency was 37.4% at 1500 rpm, compared to a predicted value of 37.7%;
- engine efficiency tends to be significantly higher than predicted for the lower mean working gas pressures (this difference decreases as mean working gas pressure is increased to its maximum value);
- engine efficiency falls slightly below predictions at low engine speeds only; and,
- peak efficiencies tend to occur at higher-than-predicted engine speeds.

Mod I Engine Fuel Consumption Comparisons

Engine efficiency is also determined alternatively on a fuel consumption basis; that is, the amount of fuel burned per unit of power delivered. Fuel consumption comparisons indicate the following:

- Mod I engine data shows a minimum of 0.37 lb/bhp-hr at 1500 rpm, as illustrated in Figure 6.
- Figure 6 also compares the Mod I fuel consumption characteristics with those of other conventional engine types (the comparisons are made at 2000 rpm).
- The Mod I is not only below these engines, but has a flatter profile, making it more adaptable to automotive application.

Mod I Stirling Engine System Data

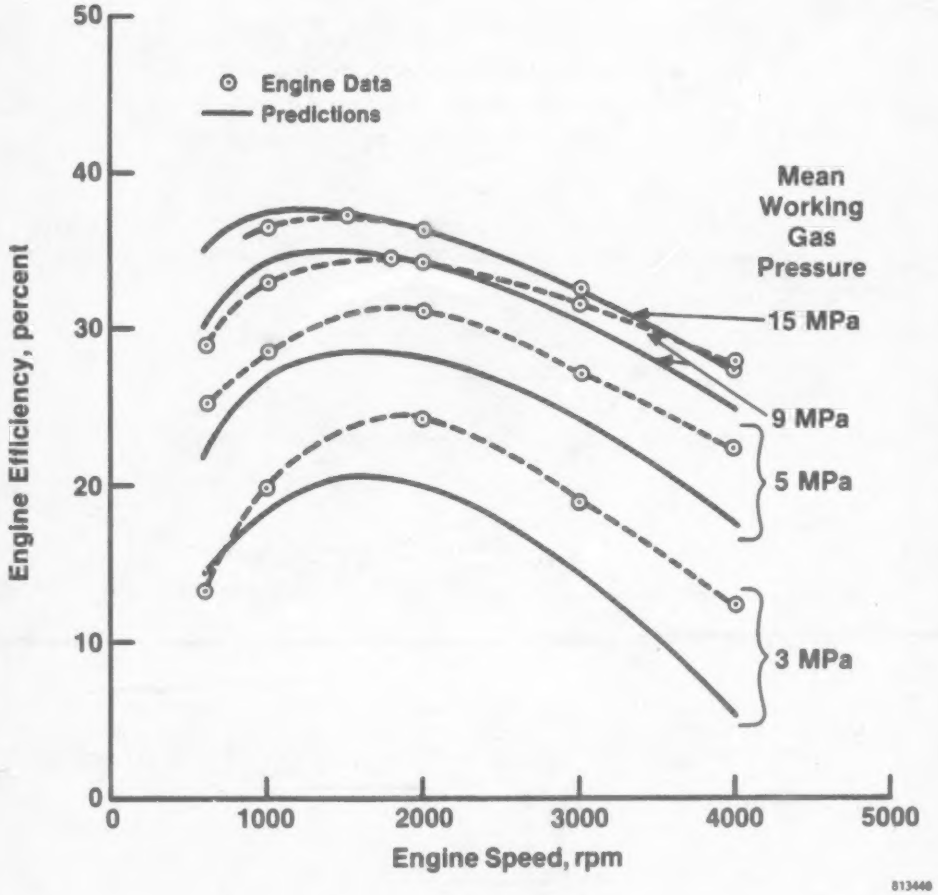


Figure 5 Mod I Stirling Engine System Efficiency Characteristics

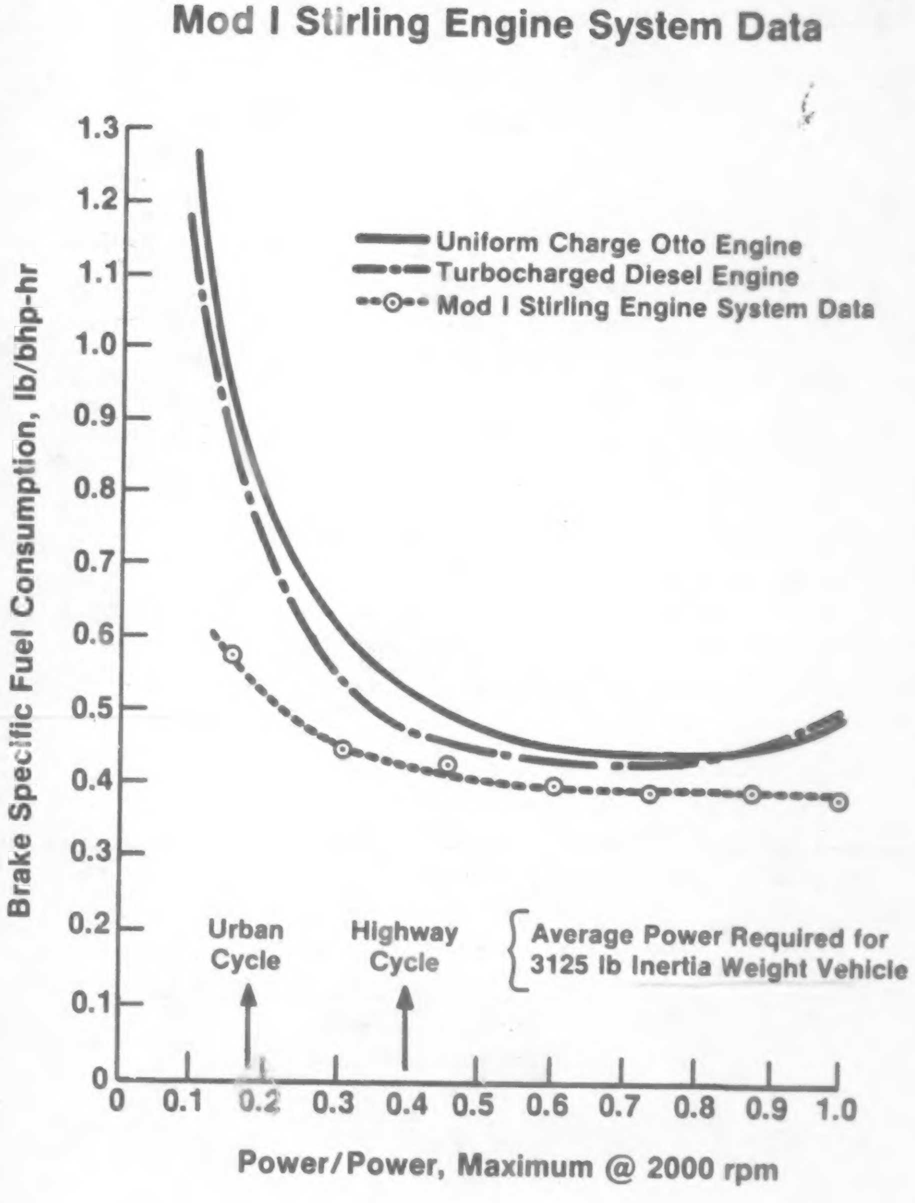


Figure 6 Engine Fuel Consumption Comparisons

Mod I Engine Torque-Speed Comparisons

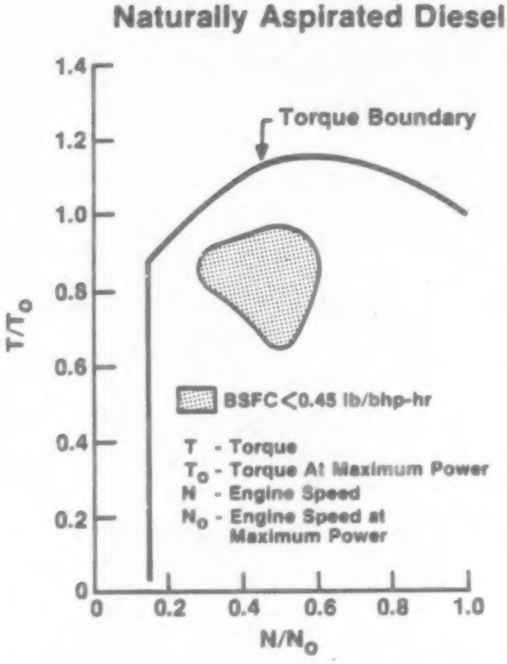
Automotive engines with a high torque ratio at relatively low engine speeds are advantageous because they exhibit better acceleration performance. The Mod I characteristics shown in Figure 7 illustrate that:

- The Mod I has a better torque characteristic compared to that of a conventional, naturally aspirated diesel engine, and for the same horsepower, the Mod I will provide better vehicle performance than a conventional engine.
- Regions were the specific fuel consumption is less than 0.45 lb/bhp-hr are identified for the two engines. The Mod I has a region seven times larger than the corresponding region for the naturally aspirated diesel engine.
- The excellent part-load fuel consumption of the Stirling engine is particularly attractive for the automotive application.

Mod I Engine Emission Data

The emission characteristics of the Mod I Stirling engine indicate that the engine is capable of meeting the following projected federal emission standards for 1985:

0.4 gm/mi	NO_x
3.4 gm/mi	CO
0.41 gm/mi	HC



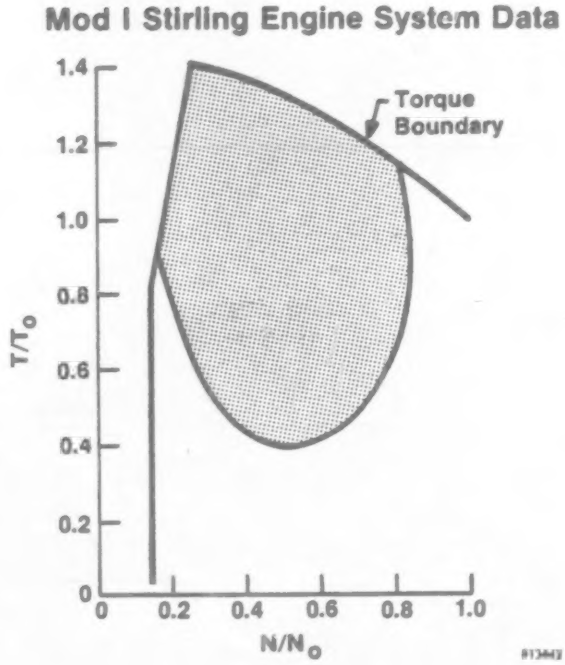


Figure 7 Engine Torque-Speed Comparisons

92-752 O—82——7

- Figures 8, 9, and 10 illustrate measured emissions data from the Mod I engine given in terms of the emission index expressed in grams of pollutant per kilogram of fuel used.

- The average value of emission indexes needed to meet the federal standard are shown for comparison purposes.

- On an average basis, the measured values indicate that the Mod I Stirling engine is capable of meeting the Federal emission standards with some margin.

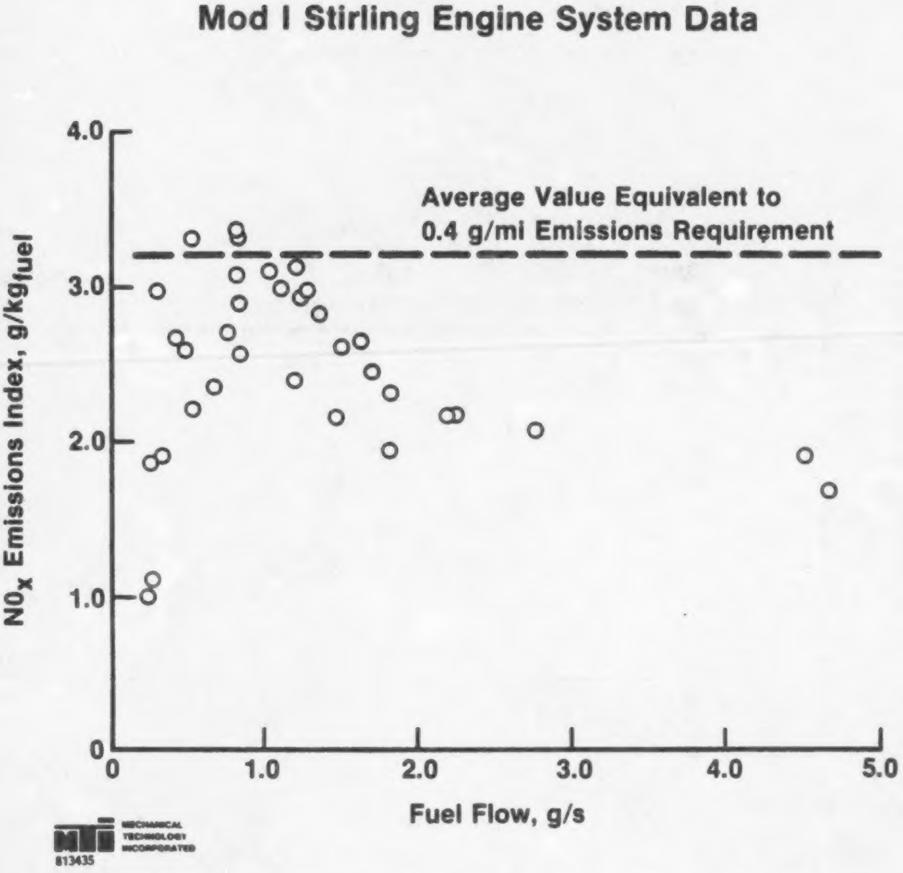


Figure 8 Nitrogen Oxide Emissions

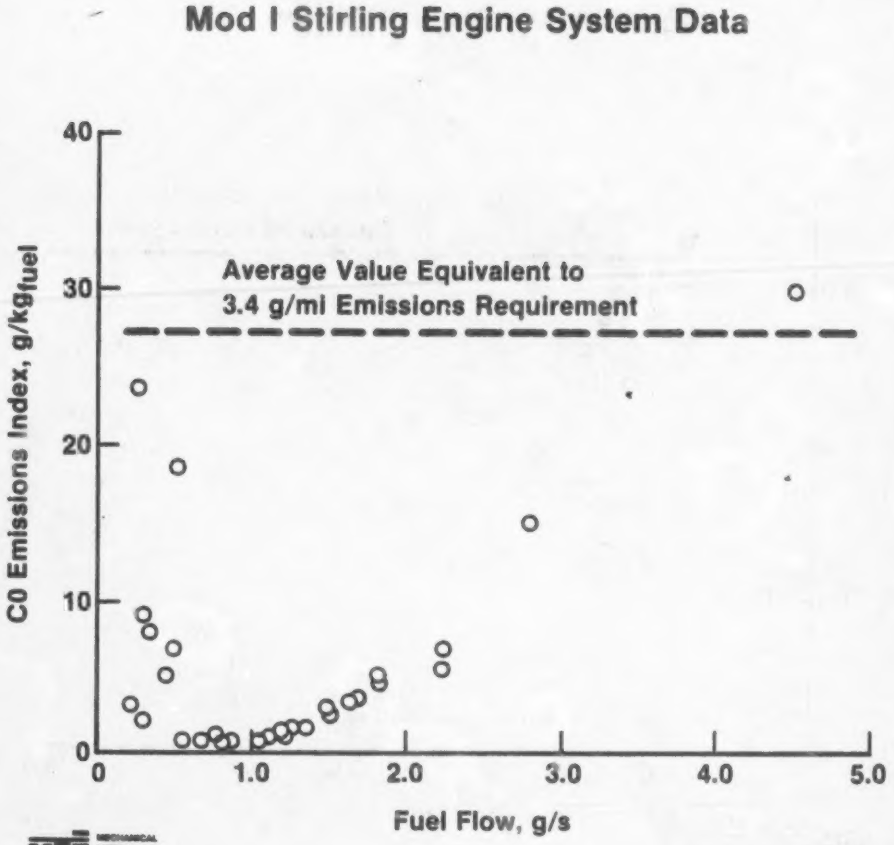


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Figure 9 Carbon Monoxide Emissions

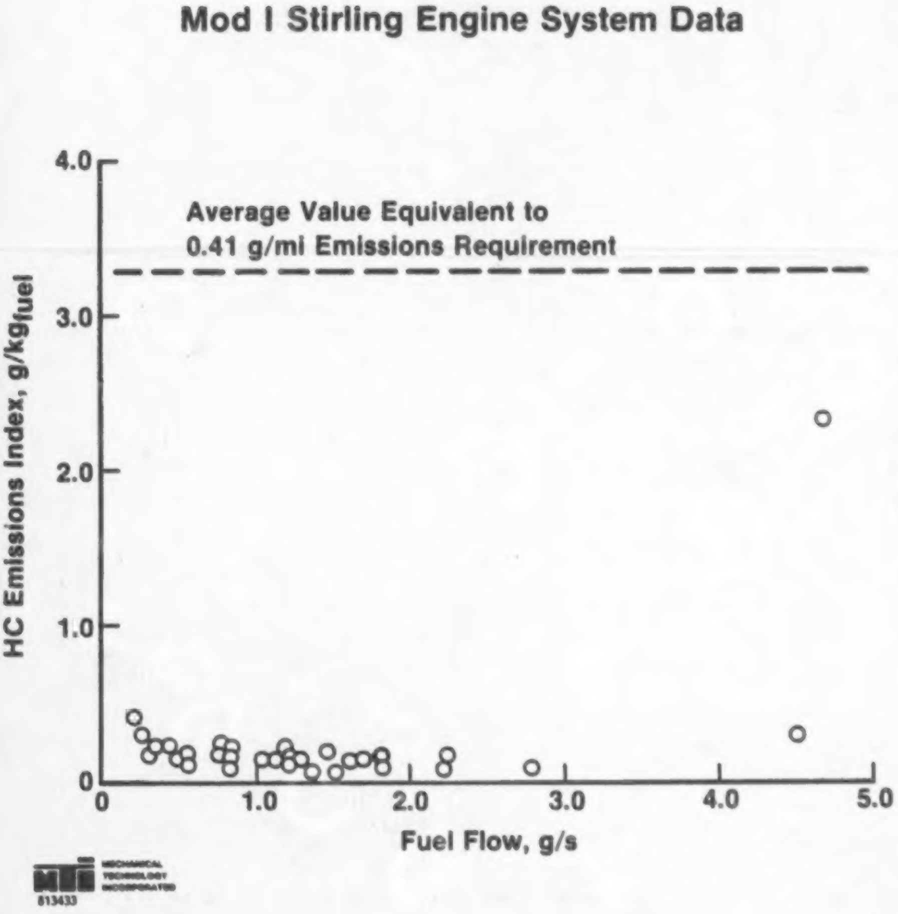


Figure 10 Hydrocarbon Emissions

MULTI/ALTERNATIVE FUELS TEST PROGRAM

Summary

During 1981, a Stirling engine was tested with five different fuels to demonstrate the engine's ability to perform satisfactorily with the fuels while maintaining acceptable emission levels.

- The fuels tested were:

    1. unleaded gasoline;
    2. commercial diesel fuel;
    3. gasohol (90%/10%);
    4. *shale-oil-derived marine-diesel fuel; and,
    5. *experimental reference-broadened-specification aviation turbine fuel (ERBS).

- Engine performance (power and efficiency) was not affected more than 10%, and engine hardware was not changed to test the engine.

- Emissions were measured, showing no significant change in its level.

---

*Obtained from a government-sponsored alternative fuels program.

TECHNOLOGY TRANSFER

Engines

The ability to manufacture, assemble, and test Stirling engines in the United States has been clearly demonstrated during the past year.

- Approximately thirty separate vendors have been established throughout the U.S.A. to support our effort. A few of the vendors and their locations are:

Investment Castings	Oregon
Crankshafts	Michigan
Brazing Fabrication	Ohio
Machining	New York/Mass./Conn.
Piston-Deep Drawing	New Jersey
Ceramics	New Jersey
Tube Bearing	Connecticut
Aluminum Casting	New York
Raw Material Tubing	Pennslyvania
Transducers	California
Stampings	Wisconsin

- A Mod I engine is currently being assembled from a majority of parts made in the U.S.A., and will be tested and characterized during the coming year.

- A Mod I engine has been installed and successfully tested in an engine call at MTI, as shown in Figure 11.

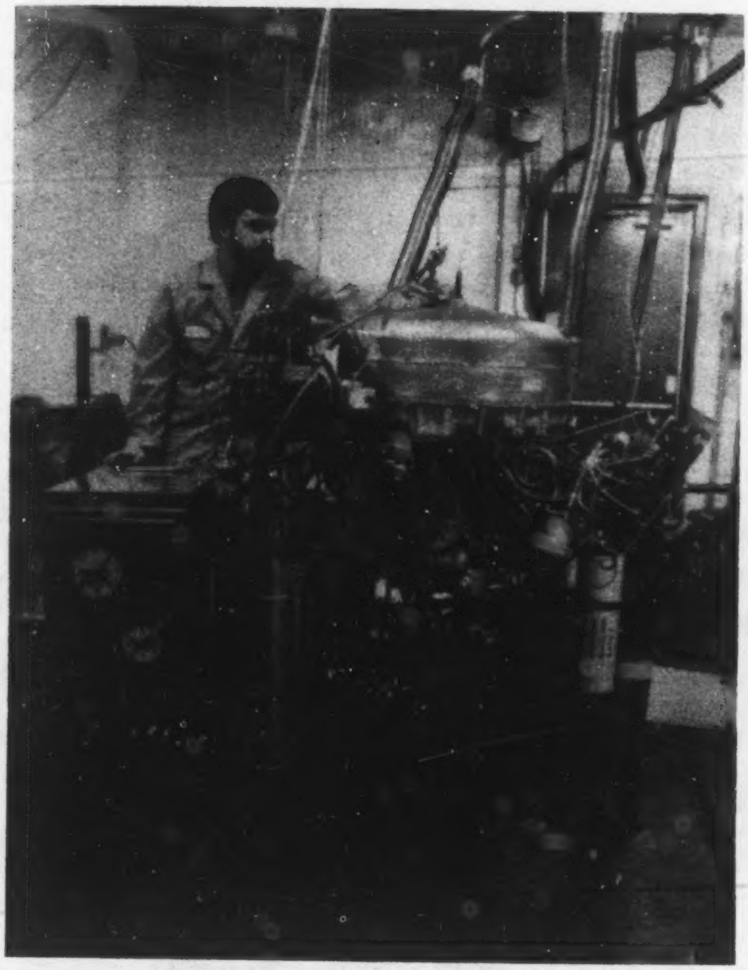


Figure 11 Mod I Engine on Test at MTI

[illegible]

The impact of these technical accomplishments in attaining the goals of Title III is illustrated in Table 1. With the extremely successful early testing of the Mod I, and conservative projections on performance improvements to be derived from the engine development program and the Mod I upgrading proposed for FY '83, attainment of the Title III goals can be safely predicted, although not in the original program time frame because of the reduced scope in FY '81 and '82.

Table 1 shows that the Mod I engine (a technology performance engine) can achieve 28 mpg combined cycle, and is 12% more efficient than today's internal-combustion engine. The Reference Engine (the preliminary Mod II design) is predicted by computer programs commonly used for this purpose to yield 41.1 mpg combined cycle - a 52% improvement over existing X-body front-wheel-drive automobiles. A simple down-sizing of this design (with no optimization) will yield 51.4 mpg in a 2250 lb subcompact vehicle - a 40% improvement. An ongoing study of other down-sized versions of the Reference Engine design holds promise for maintaining this latter mpg improvement in simpler, lower cost configurations.

The data in Table 1 convincingly show that an automotive Stirling engine can be used: 1) to achieve much more efficient use of petroleum fuels; 2) to provide personal mobility without dependence on petroleum by using indigenous fuels such as alcohol; and 3) efficiently in larger vehicles of superior crashworthiness to avoid the large increase in facilities forecast by safety experts that will result from complete down-sizing of the vehicle fleet. These conclusions argue strongly for the continued development of Stirling technology in the United States.

TABLE 1

STIRLING ENGINE VEHICLE MILEAGE COMPARISON

	Vehicle	Inertia Weight Class	Mileage		
			Urban	Hwy	Combined
IC Engine	1982 AMC	3000 lb	23	38	28
	Spirit		23	29	25
			Improvement		12%
Reference Engine	1982 X-Body	3000 lb	33.3	57.4	41.1
(Mod II)			23	33	27
IC Engine					
			Improvement		52%
Down-Sized	1982	2250 lb	40.3	77.5	51.4
Reference	Subcompact		32.7	43.6	36.8
Engine					
			Improvement		40%

NOTE: All comparisons made for identical acceleration times; unleaded gasoline.

ASE Program Status Summary

In summarizing the status report on the ASE program, despite budget reductions and small, continuous funding increments, the following accomplishments have been demonstrated:

- the program is basically on schedule and within cost;
- the Mod I engine has met and will surpass its performance goals; and,
- the transfer of Stirling technology to the United States is proceeding at a rapid rate.

Foreign Competition

It is a paradox that, while support of the United States Government for Stirling technology is receding in spite of excellent technical success, other countries are actually embarking on expanded programs. Most notable is the recent announcement by the Japanese Government of a multiyear development program as part of the "Moonlight Plan". This program was described recently in a newspaper article (included along with its English translation at the end of this testimony).

The newspaper article gives a brief but comprehensive look at Japanese interest and activities, and points out that an experimental device, Melsy 2, is already undergoing engineering test. Aisin Seiki Company is researching a 50 kW (67 hp) engine (probably for automotive application). The description of Melsy 2 indicates that the Japanese have most likely mastered basic Stirling engine technology. Further, the article's discussion of the petroleum required for Japan's automotive fleet leaves no doubt that the automotive application is their real goal.

It is worth noting that while articles describing Japan's activities in Stirling engines are now appearing in newspapers and magazines, one should not conclude that this is a new initiative. Activity has been ongoing in Japan for a number of years. The appearance of information in print probably means that program progress is such that it warrants public attention. Table 2 is from a 1979 report by W. R. Martini, respected editor of the Stirling Engine Newsletter. The table shows that during 1979 sixteen Japanese organizations were known to be engaged in Stirling engine research. The recent public announcement of a formal ten-year program suggests that the number and size of the programs have grown in the last three years. In addition, German involvement in Stirling engines has increased in the last several years, must notably at Daimler and MAN.

Table 3 was taken from "The U.S. Automobile Industry, 1980; Report to the President from the Secretary of Transportation, January, 1981", and was discussed at hearings last year before this subcommittee. The message was that, in addition to inroads made in our domestic economy by imported cars, a growing trend toward offshore production of power plants exacerbates the situation. Unfortunately, updating of this table has not been possible; however, there is no reason to believe the trend has been reversed.

The situation in the U.S. automobile industry is a notable example of a larger issue relating to our passing leadership in innovation and technology development. In the Congressional Record of Friday, December 11, 1981, Senator John Glenn cited the fact that by 1983, 50% of all cars sold in the U.S. will either be foreign-made or American cars containing foreign engines. Senator Glenn also noted that the growth in R&D spending in the United States was about 4.5%, as compared to 21% for Japan and 15% for Germany. In particular, the United States appears to be rapidly decelerating non-nuclear research in the energy field,

TABLE 2

JAPANESE COMPANIES INVOLVED IN STIRLING ENGINE TECHNOLOGY

AISIN SEIKI COMPANY, LTD.
1, Asahi-machi 2 chome
Kariya City, Aichi Pref.
Japan
Attn: Shigenori Haramura

DAIHATSU DIESEL COMPANY
1-17 Oyodo-cho 1-chome
Oyodo-ku, Osaka 531
Japan
Attn: J. Goto

JAPAN AUTOMOBILE RESEARCH INSTITUTE
6-1 Otemachi 1-Chome
Tokyo 100
Japan
Attn: H. Hayashi

MECHANICAL ENGINEERING INSTITUTE
Agency of Industrial Science & Tech.
Kikai Gijutsu Kenkyujo
4-12-1 Igusa
Suginami-ku, Tokyo
Japan

MEIJI UNIVERSITY
1-1, Kanda-Suragadai
Chiyoda-ku, Tokyo 101
Japan

MITSUBISHI HEAVY INDUSTRIES
5-1 Maronouchi 2 Chome
Chiyoda-ku, Tokyo
Japan

NEW POWER SOURCE RESEARCH DEPARTMENT
Central Engineering Laboratories
1 Natsushima-cho, Yokosuka 237
Japan

NIPPON PISTON RING COMPANY, LTD
No. 1-18, 2-Chome
Uchisaiwaicho, Chiyoda-ku, Tokyo
Japan

SHIP RESEARCH INSTITUTE
6-38-1
Shinkawa, Mitaka, Tokyo 181
Japan

SHIPBUILDING RESEARCH ASSOC. OF JAPAN
Senpaku Shinko Building, 1-15-16
Toranomon, Minato-ku, Tokyo
Japan

TOKYO GAS COMPANY, LTD.
1-2-16 Yaesu
Chuo-ku, Tokyo 103
Japan
Attn: M. Ogura

TOKYO INSTITUTE OF TECHNOLOGY
Naotsugu ISSHIKI (laboratory)
2-12-1 Ookayama Meguroku, Tokyo 152
Japan

UNIVERSITY OF TOKYO
Department of Mechanical Engineering
Hongo 7-3-1
Bunkyo-ku, Tokyo 113
Japan
Attn: Naomasa Nakajima

UNIVERSITY OF TOKYO
Department of Mechanical Engineering
Hongo 7-3-1
Bunkyo-ku, Tokyo 113
Japan
Attn: Masaru Hirata

UNIVERSITY OF TOKYO
Faculty of Engineering
Department of Nuclear Engineering
Hongo 7-3-1
Bunkyo-ku, Tokyo 113
Japan
Attn: Yoshihiro Ishizaki

YAN MAR DIESEL ENGINE CO., LTD.
62, Chaya-machi
Kita-ku, Osaka 530
Japan

TABLE 3

FOREIGN SOURCES - RECENTLY ANNOUNCED COMMITMENTS BY U.S. AUTOMOBILE MANUFACTURERS TO PURCHASE FOREIGN-MADE COMPONENTS FOR USE IN DOMESTIC VEHICLES PRODUCTION

Automobile Manufacturer	Description of Component	Intended Use	Manufacturing Source	Approximate Number of Components	Period
G.M.	2.8 liter Y-6	Cars	GM de Mexico	< 400,000/year	1982-
	2.0 liter L-4 with transmission	Mini trucks	Isura (Japan)	100,000/year	1981-
	1.8 liter diesel L-4	Chevette	Isura (Japan)	small numbers	1982-
	1.8 liter L-4	J-car	GM de Brazil	250,000/year	1979-
	TMM 180 automatic transmission	Chevette	GM Strasbourg (France)	-250,000/year	1979-
Ford	2.2 liter L-4	Cars	Ford-Mexico	< 400,000/year	1983-
	diesel L-4	Cars	Tokyo Kogyo	150,000/year	1983-
	2.0 liter L-4	Mini trucks	Tokyo Kogyo	< 100,000/year	1982-
	2.3 liter L-4	Cars	Ford de Brazil	- 50,000/year	1979-
	Diesel 6 cylinder	Cars	BMW/Stager	100,000/year	1983-
	Turbo-diesel/4 cyl.	Cars	BMW/Stager	-	1985-
	Manual transaxles	Front-Disc Cars	Tokyo Kogro	100,000/year	1980-
	Aluminum Cylinder Heads	1.6 liter L-4	Europe, Mexico	-	1980-
	Electronic Engine Control Devices	Cars	Toshiba	100,000+/year	1978-
	Ball Joints	Cars	Masashi Seimibu	1,000,000/year	1980-1984
Chrysler	L-6 and V-8 engines	Cars	Chrysler de Mexico	< 100,000/year	early 1970's
	2.2 liter L-4	K-body	Chrysler de Mexico	< 270,000/year	1981-
	2.8 liter L-4	K-body	Mitsubishi	1 million	1981-1985
	1.7 liter L-4	L-body (Omni)	Volkswagen	1.2 million	1978-1982
	1.6 liter L-4	L-body	Talbot (Peugeot)	400,000 total	1982-1984
	2.0 liter Diesel Y-6	K-body	Peugeot	100,000/year	1982-
	1.4 liter L-4	K-body (Omni replacement	Mitsubishi	300,000/year	1984-
	Aluminum Cylinder Heads	2.2 liter L-4	Fiat	-	
AMC	Car Components and Power Train	AMC-Renault	Renault in France and Mexico	300,000/year	1982-
VW of America	Radiators, Standings	Rabbit	VW de Mexico	250,000/year	1979-
	L-4 diesel and gas	Cars	VW de Mexico	300,000/year	1982-

while most other countries are accelerating their efforts. The difference in emphasis on energy policy is of concern since Japan and Europe have traditionally had higher energy costs and have been more sensitive to the need for energy efficiency than the United States; i.e., they have perceived and reacted to the "market signals" earlier and faster than the United States. Their increased effort in multifuel engines suggests that their view of the world oil supply is inconsistent with the United States energy policy. The question is "why"?

Jean-Jacques Servan-Schreiber has written a treatise on the key role of oil in world economics and policitcal power entitled, "The World Challenge." Servan-Schreiber points out that oil is the key to the mobility of the world's 350 million trucks and cars. Further, it is the feedstock for the plastics, synthetic fibers, insecticides, fertilizers, paint, medicine, detergent, and adhesives industries. It is also the dominant force in agriculture and a major factor in electricity production. In short, oil is the basis for modern man's transportation, heating, electricity, and agriculture. All of this has come about in a remarkably short period of time - about 30 years. Servan-Schreiber attributes the lack of ability of the industrialized nations to effectively deal with crude oil problems to the fact that our dependence has become almost total in such a brief time, that we have not recognized the magnitude of the shift of power and economic strength to the oil-producing sectors of the world.

Despite recent easing in the price of gasoline, there is still a compelling reason for the industrialized nations to lessen their dependence on the finite pool of available crude oil. There are several ways to accomplish this, including conservation and improved efficiency. The Stirling engine has demonstrated its ability to substantially improve the efficiency of personal mobility using a variety of fuels, including nonpetroleum sources such as alcohol. Further, continuation of the ASE program allows the establishment of a critical mass of trained engineers and vendors to support a broader development of Stirling-powered products. In addition to automotive applications, these include electrical generator sets, heat pumps, and solar-powered units. Without the base of the ASE program, the United States may find itself unable to compete with foreign products not only in the automotive area, but in every current application that involves a spark-ignition or compression-ignition heat engine as a prime mover. Against this background, MTI requests that the Congress provide $12 million for the FY '83 program (i.e., a total of $14M to DOE).

PROPOSED FY '83 PROGRAM

The program that we propose for FY '83 builds on the excellent initial success of the Mod I engine and emphasizes the development of the characteristics that will contribute to industrial acceptance of this technology. Specifically, the 1983 program will include the following initiatives:

- Through a comprehensive engine test program, the Stirling engine will be proven in regard to reliability and durability requirements of the automotive application.
- Marked improvements will be made to the Stirling Engine System as it applies to:
    - performance and fuel economy;
    - manufacturing cost;
    - small-vehicle packageability; and,
    - manufacturing techniques.
- Proof of its transient capabilities (as applied to the automotive application) in acceleration, cold-weather operation, and emissions will be established, and alternative fuel evaluations will continue.
- This proof-of-concept program will be made possible in a very cost-effective manner, since existing engine hardware will be used in a majority of cases.
- Final demonstration of the transfer of Stirling engine technology will be accomplished through design, manufacture, assembly, test, and development.

In addition, a special initiative will be made to involve the domestic automobile industry in this program. With the favorable initial acceptance of the Mod I data, we believe it is now possible to set up a constructive dialogue with the industry. In particular, we will ask the industry to identify and quantify the operating goals that will be most meaningful to them in assessing the future role of Stirling engines in their product lines. In our opinion, the time has come for the industry to tell the Government what performance levels must be met in order to progress toward a viable alternative power plant.

SUMMARY

In conclusion Mr. Chairman, I would like to summarize the following:

1. The ASE program is a successful example of the type of program that should be supported by the Federal Government to address major national needs. The ongoing program will probably exceed the technical goals established for the Mod I engine.

2. Stirling engine technology is receiving increased attention and support by foreign governments, which may lead to a broad array of energy-efficient products that cause further domestic economic dislocation.

3. There is no evidence that U.S. industry is in a position to pursue this technology without substantial Government support. We ask the automotive industry to get involved to the extent of suggesting specific goals to DOE and NASA for the FY '83 program.

4. The original goals of Title III of PL 95-238 are still valid and in the public's interest. A second-generation commercializable Stirling engine can be realized within the funding estimates for the original program, although the time frame will have to be adjusted because of the reduced effort in FY '81 and '82.

APPENDIX

Translation of Japanese Newspaper Article

Translation of the Newspaper Article on the Stirling Engine with Coal, Heat Waste, or Solar Energy

Development of the Stirling engine, which is hoped to be a "post-petroleum" power source, has come into being. This engine is not like the internal-combustion engines being used in today's cars, rather it is an external-combustion engine having a completely different structure from anything seen until now, which can use coal and just about any other type of fuel. Moreover, it is blessed with high efficiency, makes little noise, and has no vibration. The Machine Technology Research Center of the Industrial Technology Institute is test producing one machine, Melsy 2, and in addition to confirming its utility through driving tests, Aisin Seiki and other large companies are moving ahead on its research. However, technologically there are many points that must be solved before it is ready for full use. Accordingly, the Industrial Technical Division of the Ministry of International Trade and Indsutry (MITI) has set up the Stirling engine project as a part of its "Moonlight Plan" starting in 1982. MITI will invest approximately 10 billion yen for development over a ten-year period, and plans to carry out research that will bring about its full utilization.

Almost all of the engines being used in today's cars are internal-combustion types in which the pistons are pushed down and the crank is moved in accordance to the explosive power of the fuel supplied to the inside of the cylinder. In contrast to this, the external-combustion Stirling engine operates by mixing gases such as hydrogen and helium in the cylinder, and moves the piston and crankshaft according to temperature and pressure differences resulting from outside heating and cooling. In other words, as indicated in diagram (1), the gas trapped inside the cylinder expands by combustion heat from outside, pushing down on the generating piston; (2) in one of the cylinders gas pressure is lowered by outside cooling, which raises up the piston and then compresses. Through continuous repitition of the action described in steps 1 and 2, the crankshaft is propelled.

Accordingly, the Stirling engine, (1) in contrast to the internal-combustion engine which utilizes such fuels as gasoline, lightweight oil, and LNG, can possibly use nonpetroleum fuels such as coal, solid fuel, factory heat waste, or solar energy. A diversification of heat sources is planned (2) because there is no explosive process vibrations and noise does not exist, making it quiet. (3) It is also said to have the special characteristics of being able to easily control gas waste, and being highly heat efficient.

The history of the invention of the Stirling engine is old. Original work on it was done in 1816 by the English pastor, Robert Stirling. However, it disappeared from sight with the arrival of the internal-combustion and steam engines in the nineteenth century. The primary reasons for its disappearance were that the Stirling engine's technology at that time was not fully developed, nor was development of its material technology. Recently, this technological development is proceeding at a rapid rate and, along with this, we are re-examining its low polluting factors such as low vibration, low noise level, and diversability of its fuel. Starting with our country (Japan), other countries as well in Europe, and the U.S., have commenced research to realize its utilization. In America, the Department of Energy (DOE) has appropriated 100 million dollars and is proceeding with research development of a 65-kilowatt Stirling engine for automobile use. By 1984, the DOE is planning to conduct a load-proving test and, in addition, as part of its external-combustion engine project, is carrying out development of a large-scale Stirling engine (500-300 horse power)

In experiments under conditions with heater temperatures of 680°C and average pressure of 10-33 atm, output reached 750 revolutions per minute; at 33 atm, 1.4 kilowatts of output was obtained.

In addition to the 2-piston Melsy 2 model, there are 3 other types of Stirling engines. First is the double-acting model, in which the upper and lower parts of the adjoining cylinder are joined to become the heating and cooling parts; next is the displacer model in which the operating fluid is made to move between the cooling and heating parts inside one piston; and third is the free-piston model. However, in all cases there are current major problems remaining which are: (1) in order to use helium and hydrogen as operating gases, seal technology must be further developed to provide greater durability and prevent leaks; (2) in order to improve heat efficiency, heating and storage devices with better capacity, as well as combustion devices of greater durability, must be developed.

In addition to overall establishment of a Stirling engine system and improvement in fundamental engine technology (such things as seal apparatus and heat exchange devices), the Moonlight Plan is speeding up research development on fuel diversification (natural gas, coal, etc.) and, after 1983, is aiming at completion of a small helium-style Stirling engine (10 to 50-kilowatt class) intended for general use by consumers and industry.

Of all the energy currently consumed, the petroleum-using heat engines take up a great share, so the greatest topic nowadays in many countries is how to cut down on and diversify energy usage. In 1980, our country (Japan) consumed over 57,000,000 kiloliters of light oil and gasoline for automobile usage, accounting for 25% of the total petroleum consumption for the country. Moreover, even though improvements have been added to engines in recent years, the which will use not only coal but also municipal and industrial waste products as fuel. European countries are in the midst of developing the Stirling engine for respective reasons. The Philips Corp. of Holland wants to use it for heat pumps; the United Stirling Co. of Sweden wants it for automobile and electric generating equipment; and West Germany's Mann Corp. wants it for use in large-scale ships.

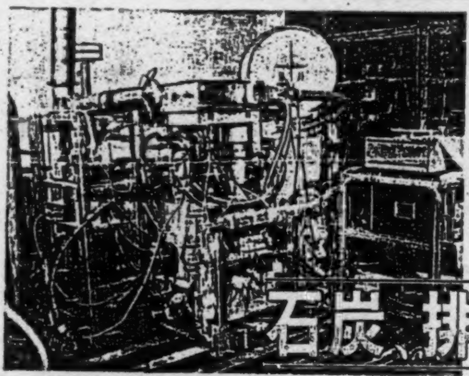
To these ends, our country's Machine Technology Research Division of MITI has test produced the Stirling engine experimental device, Melsy 2, which is now at the stage where it's undergoing experimental driving tests. Aisin Seiki is also test producing and researching a 50-kilowatt class Stirling engine, but in both cases, actual utilization has not been achieved.

Under these circumstances, the Machine Technological Research Center of MITI's Industrial Research Division has started with Melsy 2 as a base and, starting in 1982, has taken up the new project (as part of the Moonlight Plan) of developing the Stirling engine as an energy-stingy device capable of using petroleum substitutes. The final goal is its full-scale commercial utilization. The Melsy 2 model test produced by the Machine Technical Research Division consists of 2 pistons; and the piston and crank systems consist of 2 sets: the expansion and compression sides. They are continually combined by means of a variable-coupling device (phase differential = 90°) between them. The diameter of the piston is 80 mm. In the heater part, 22 narrrow stainless tubes (SUS 310S), which have an internal diameter of 4 mm and a length of 420 mm, are arranged in the style of a roof, while in the cooler part 22 narrow bronze tubes (internal diameter 1.5 mm; length 100 mm) are piled up in the shape of a bundle. A heat-storing device (regenerator) used to store excess heat is 86 mm in diameter and 54.6 mm in. thickness, and is made of a wire netting layer.

heat efficiency ratios of gasoline and diesel engines, (using light oil) have not exceeded the 25% and 30% levels, respectively. On this point, there are still many technical questions remaining about the Stirling Engine, but Energy Section Chief, Mr. Iwao Yamashita, of MITI's Machine Technology Research Center, says it is possible to attain a heat efficiency ratio of close to 40%. The evidence is rather strong that the Stirling engine will be a "future-generation engine" that will run on nonpetroleum fuel.

MITI's Industrial Technology Division is currently looking into the possibility of introducing a "Unified Research Policy" to reach its goal, and much is to be expected as our country again further steps up its efforts to develop an adequate Stirling engine.

日刊工業新聞 (12/)



“[illegible]”を目指した新しい動力源・スターリングエンジンの開発が本格化してきた。このエンジン、在来の自動車エンジンにみられるような内燃機関でなく、外燃機関というこれまでとは全く異なった構造のもので、使用する燃料も石油はもとよりどんな燃料でも使え、しかも高効率で騒音、振動が少ないのがメリット。工業技術院機械技術研究所がその一号機「メルセⅡ」を試作、基礎実験で実用性を確認したのを初め、アイシン精機など各メーカーでも研究が進められている。ただ、実用化までには技術的に解決すべき点も多い。そこで通産省工技院では五十七年度から“ムーンライト計画”の一環としてスターリングエンジンをプロジェクト化、十年間に約百億円の研究費を投入、本格的な実用化研究に取り組む方針である。

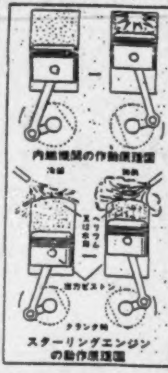
石炭、排熱、太陽熱でも

先端技術

スターリングエンジン

外燃構造で高効率
騒音、振動も少ない

[illegible]



スターリングエンジンの動作原理図

試作機で実用性確認
工技院 10年間、100億円投入へ
ポイントは燃焼器開発

[illegible]

レッサー
株式會社

新刊
「モータのマイコン制御」

コンピューターを使った名簿づくり
164,000人

1983 DOE AUTHORIZATION

WEDNESDAY, MARCH 3, 1982

House of Representatives, Committee on Science and Technology, Subcommittee on Transportation, Aviation, and Materials,

Washington, D.C.

The subcommittee met, pursuant to adjournment, at 10:02 a.m., in room 2318, Rayburn House Office Building, Hon. Dan Glickman (chairman of the subcommittee) presiding.

Present: Representatives Glickman, Harkin, Shamansky, Dunn, Hollenbeck, and Carney.

Mr. Glickman. The subcommittee will be in order.

Today we continue our hearings on the transportation programs within the Department of Energy. Yesterday we heard from a variety of industry witnesses, including representatives of the Ford Motor Co. and General Motors, who essentially indicated their support for the heat engine programs. I think that it would be a fair statement to say they indicated their support because of the precarious nature of the automobile industry right now. They could not—and I repeat, could not—undertake those tasks were it not for the basic Government programs of support.

In addition to that, they indicated to this committee that the increase in support by the Japanese Government, especially, was rather dramatic, particularly in the heat engine and ceramics areas.

So today we will hear from witnesses from the administration, who will give us their rationale for the President's budget, which, in the transportation area, essentially zeroes out all the programs.

I might tell you, so you have some idea where I am coming from, that I did not read the President's budget in transportation or your statement with great enthusiastic support. So I would hope that you would be able to give as strong a rationale as you possibly can for where the administration is coming from.

I might again tell you, before you begin, that the industry, the auto industry in America, is very, very sick. Basically, the implication I got from them yesterday was all the tax credits in the world—and I supported the tax bill —are not going to help them, basically, over the next several years in doing the kind of long-term basic research that the Japanese Government is helping their companies do.

So, given that kind of subjective orientation on my part, I would be glad to let you proceed now.

But, before you do, Congressman Dunn, do you have any comments?

Mr. DUNN. No.

Mr. GLICKMAN. Congressman Carney?

Mr. CARNEY. No, sir, Mr. Chairman.

Mr. GLICKMAN. All right. Why don't we go ahead and begin, then.

STATEMENT OF JOSEPH J. TRIBBLE, ASSISTANT SECRETARY FOR CONSERVATION AND RENEWABLE ENERGY, U.S. DEPARTMENT OF ENERGY, ACCOMPANIED BY MAXINE SAVITZ, DEPUTY ASSISTANT SECRETARY

Mr. TRIBBLE. Thank you, Mr. Chairman.

I appreciate your frankness, and I hope that I will be able to give you some information that will justify the positions that we have taken.

I am pleased to have with me today Dr. Maxine Savitz, who is the Deputy Assistant Secretary, and her staff, because they certainly are a knowledgeable group and can provide me with the answers of questions that you may ask that I do not know the answers to.

So it is a pleasure to be here and to have this opportunity to appear before you and to discuss this subject.

The Electric and Hybrid Vehicle Development and Demonstration Act of 1976 was passed during a time of continuing escalation of prices of petroleum and in a period of increasing dependency upon foreign sources for this petroleum. In response to the congressional mandate, an intensive effort was begun to develop an electrically driven vehicle.

During the past several years, the technical performance capability of electric vehicles has been significantly advanced. When the program began, the urban driving range of a typical electric vehicle was on the order of 30 miles. In 1981, a range of 70 miles was achieved, and we may look forward to an extension of this range to more than 100 miles by 1984.

There has been meaningful progress in adapting the lead-acid battery to vehicle propulsion use. There has also been extensive research into other types of batteries which are expected to be more appropriate for vehicular use in the future.

At this time, electrically driven vehicles are available for purchase by the general public. However, interest to date has been greater among fleet operators and for special-purpose vehicles.

The crisis conditions which existed in 1976 fortunately do not exist today. Prices for petroleum fuel have stabilized, and our dependence on foreign crude is no longer increasing but in fact has diminished markedly. We therefore feel that it is appropriate that the Federal Government no longer pursue the development of electric vehicles. We do feel that it is appropriate for the Federal Government to continue to participate in the further development of electrochemical storage. This work will be beneficial not only to vehicular propulsion but also to extending the availability of electric power generated by wind machines and photovoltaic systems.

The Automotive Propulsion Research and Development Act of 1978 was passed under conditions even more severe than those which existed in 1976. In response, efforts were undertaken to make major improvements in the efficiency of petroleum-propelled vehicles. Research and development work has been done to build gas turbine engines suitable for automotive use. Work has also been done to determine whether or not the Stirling engine could be adapted to automotive use.

By the end of fiscal year 1982, it is expected that all-metal prototypes of two designs of automotive gas turbines will have been tested on a dynamometer. Further development of this automotive gas turbine engine will depend largely upon the substitution of ceramic components for existing metal components in the high-temperature sections of the engine.

We therefore find that it is appropriate to terminate the Federal Government participation in the building of the engine but to continue research that will lead to abilities to produce ceramic components which can be successfully introduced into these engines.

The Stirling engine is a concept which has been known for many, many years. This concept has the advantage of fuel flexibility and possibly increased efficiency. On the other hand, there are many disadvantages to its use, particularly for vehicular propulsion.

The weight-to-horsepower ratio, although it has been reduced drastically in the last few years, is still approximately twice that of a conventional internal combustion engine. To assume that this differential would be significantly narrowed beyond the present state of the art is to simultaneously assume that corresponding progress will not be made in improving the weight-to-horsepower ratio of internal combustion engines.

The Stirling engine depends upon the use of either hydrogen or helium at pressures in excess of 1,000 pounds per square inch. It also depends upon temperatures that are the upper limits of presently available metals. Expensive alloys using comparatively scarce materials are therefore required. This engine does not lend itself to substitution of ceramic components in these high-temperature areas because of high pressures of the operating medium.

The Stirling engine concept is entirely different from that of the internal combustion engine. No infrastructure exists for the maintenance of such an engine in general use. The current situation, therefore, is that a Stirling engine can be built, but it appears to have little opportunity to penetrate the market because of these disadvantages. Consequently, we feel that there is no reason for the Federal Government to continue to spend money on the Stirling engine.

The alternative fuels utilization program was structured to develop an understanding of the characteristics of potential nonpetroleum alternative fuels and to assess the effect of such fuels on the performance, emissions, durability, and reliability of engines.

A technology and information data base has been established for alcohol fuels. The data base contains operational data for methanol and ethanol, both straight and blended, and provides industry with information on fuels and engine problems for their use in commercialization decisions.

New efforts on methane fuel/engine investigations, now underway, will add to the existing data base to provide a position comparable to that now available for alcohols.

While no synthetic fuels are competitive with petroleum at current prices, establishment of the basic resources, mechanisms and facilities to formulate fuel compositions for synthetic fuels test programs is being completed so that industry will be able to carry out R. & D. activities on synthetic fuels when it determines that such additional work is warranted. Under present conditions, we see no reason for additional Federal funding of this activity.

Mr. Chairman, I have some additional information that I would like to present to you and the committee that I am sorry I did not have in time to put into this. I would like to give you copies of it now, if I may, and discuss it very briefly.

Mr. **Glickman**. Sure. Why don't you see if you can get somebody to distribute that? Is it in typewritten form or something?

Mr. **Tribble**. It is a table and typewritten page, yes.

Mr. **Glickman**. Why don't you go ahead and proceed, Mr. Tribble.

Mr. **Tribble**. All right.

This is some data that has been recently developed by people at DOE, and it shows the historical improvement in fuel economy in the automobile fleet in recent years, on up through 1980 and 1981.

As you can see there, the adjusted new-car economy, which is the center graph line, is that on-the-road experience of the new cars. The miles per gallon have risen from 13.9 in 1975 to 22.3 in 1981, which is, of course, quite an improvement.

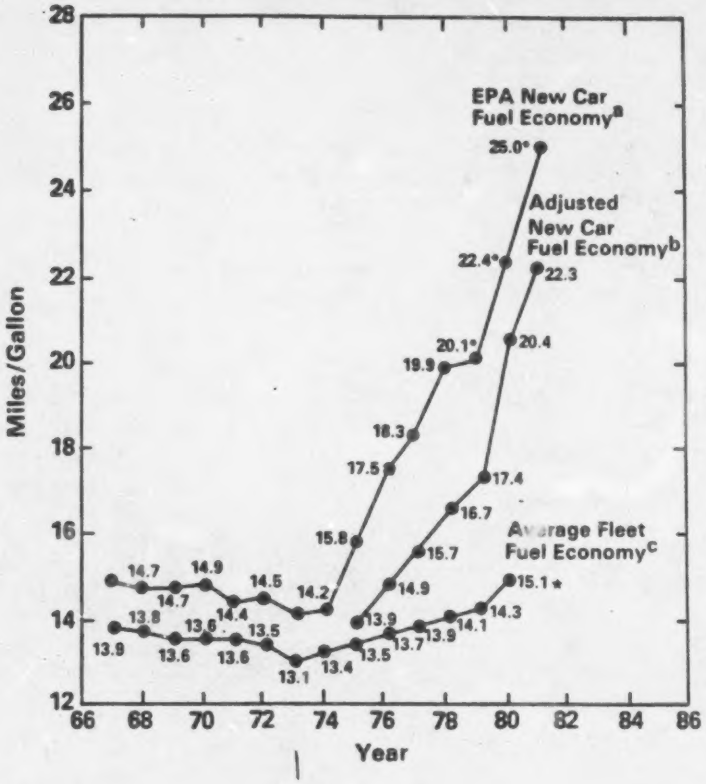
I draw your attention to the last bullet on the typewritten sheet that accompanies this. This is some information from Oak Ridge National Laboratory. If you will look, please, at the last sentence in that bullet, the most important factor contributing to increased fuel efficiency in that last 2 years has been technological improvement, comprising 65 percent of the improvement made between 1979 and 1980, and 75 percent of that made between 1980 and 1981.

I did want to include this because I think it is important for us to recognize that, although the Government has been putting some moneys into the development of technologies that we hope will be worthwhile to the automotive industry, the automotive industry has itself not been standing still. They have certainly made fine progress, and this is simply a characterization of that progress.

Thank you, Mr. Chairman.

[The information follows:]

Exhibit 22: Automobile Fleet Fuel Economy U.S. Passenger Car Fleet



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* Based on manufacturers' sales projections

★ DOE estimate. B.D. McNutt, Assistant Secretary for Conservation & Renewable Energy's Office of Vehicles & Engines

Sources: [a]J.D. Murrell, J.A. Foster, and D.M. Bristor, Environmental Protection Agency, Passenger Car and Light Truck Fuel Economy Trends through 1980, SAE Paper 800853.

[b]B.D. McNutt, H.T. Adams, and R. Dulla, Comparison of EPA and In Use Fuel Economy for 1974-1978 Automobiles: An Analysis of Trends, SAE Paper 790932. (Calculated using a slight variation of EPA fuel economy standards).

[c]U.S. Department of Transportation, Federal Highway Administration, Highway Statistics, Washington, D.C., annual.

KEY POINTS

EXHIBIT 22: AUTOMOBILE FLEET FUEL ECONOMY--U.S. PASSENGER CAR FLEET

- EXHIBIT 22 PICTORIALLY COMPARES TRENDS IN AVERAGE FLEET FUEL ECONOMY FROM 1967 TO 1980 WITH EPA NEW CAR FUEL ECONOMY FIGURES AND DOE'S ADJUSTED NEW CAR FUEL ECONOMY FIGURES.

- SIGNIFICANT IMPROVEMENTS HAVE BEEN MADE IN EPA NEW CAR FUEL ECONOMIES SINCE 1974. DOE HAS CALCULATED ADJUSTED FIGURES TO MORE CLOSELY APPROXIMATE ACTUAL IN-USE FUEL ECONOMIES. DOE'S FIGURES SHOW ROUGHLY THE SAME RATE OF IMPROVEMENT IN NEW CAR EFFICIENCIES, BUT THEIR MPG ESTIMATES ARE LOWER THAN THE EPA'S, WHOSE ESTIMATES ARE BASED ON TEST RESULTS RATHER THAN IN-USE PERFORMANCE.

- DESPITE THE ABOVE-MENTIONED IMPROVEMENTS IN NEW CAR FUEL ECONOMY, AVERAGE FLEET FUEL ECONOMY ROSE SLOWLY AFTER 1972 DUE TO THE LARGE NUMBER OF INEFFICIENT OLDER CARS STILL ON THE ROADS. AS THIS OLDER STOCK IS RETIRED AND REPLACED WITH MORE FUEL-EFFICIENT NEW CARS, HOWEVER, MARKED IMPROVEMENTS IN FLEET FUEL ECONOMY WILL SHOW UP.

- ACCORDING TO RECENT STUDIES BY OAK RIDGE NATIONAL LABORATORY, VERY LITTLE OF THE SIGNIFICANT IMPROVEMENTS IN FUEL-EFFICIENCY MADE IN THE LAST TWO YEARS IS ATTRIBUTABLE TO CONSUMER SHIFTS TO SMALLER CLASSES OF VEHICLES. OF THE TOTAL IMPROVEMENT IN U.S. FLEET MPG MADE BETWEEN 1979 AND 1980, ONLY 14% IS DUE TO SHIFTS TO SMALLER CLASSES OF VEHICLES. FOR 1980 TO 1981, THIS FIGURE IS EVEN SMALLER -- A MERE 4%. THE MOST IMPORTANT FACTOR CONTRIBUTING TO INCREASED FUEL-EFFICIENCY IN THE LAST TWO YEARS HAS BEEN TECHNOLOGICAL IMPROVEMENT, COMPRISING 65% OF THE IMPROVEMENT MADE BETWEEN 1979 AND 1980, AND 75% OF THAT MADE BETWEEN 1980 AND 1981.*

Mr. **Glickman**. Thank you, Mr. Tribble.

What I am going to do, if you do not mind, since we only have two witnesses today, is to ask Jack Kerrebrock to give his testimony now, so that you can both be on the podium for questions and answers at the same time.

Jack, your entire statement will appear in the record. If you deem it appropriate to summarize, it will be fine with us.

STATEMENT OF DR. JACK L. KERREBROCK, ASSOCIATE ADMINISTRATOR, AERONAUTICS AND SPACE TECHNOLOGY, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. **Kerrebrock**. I would like to present some results of the program. It will be fairly succinct.

Mr. **Glickman**. All right. Your entire statement will appear in the record at the conclusion of your oral presentation.

Dr. **Kerrebrock**. It is a pleasure for me to appear before the subcommittee today to discuss progress in the automotive research projects NASA is managing for the Department of Energy. As you know, except for the electric and hybrid vehicle systems technology and a few other minor activities at the Jet Propulsion Laboratory, the Lewis Research Center has the major responsibilities for this work. Significant progress has been made by Lewis in the past year in the gas turbine and Stirling engine projects; and, at JPL, we are approaching an important technology benchmark in hybrid vehicle development. Today, I will be reviewing the progress in these projects and others we are supporting for the Department of Energy, and I will briefly discuss our future plans to support these programs.

Let me first talk about heat engines. The technical objectives of the automotive gas turbine and Stirling engine projects are to provide the technology for a 30-percent improvement in fuel economy over equivalent spark ignition engines, emissions below Federal research goals, and multifuel capability. For the gas turbine to meet the fuel economy objective, uncooled high-temperature ceramic components must be developed, and compressor and turbine aerodynamic efficiencies need to be advanced beyond those previously obtained in small turbine engines.

Development of ceramic component technology [fig. 1] in support of the gas turbine project began in 1976 with the award of a contract to Detroit Diesel Allison [DDA]. In the past year, DDA has continued its efforts to fabricate and qualify the test rigs ceramic components needed for operation of the existing 300-horsepower engine at 2,070° F. turbine inlet temperature. This figure shows these components, and each has been successfully tested in component test rigs to confirm its suitability for engine use except for the turbine inlet plenum that requires additional testing. We expect the 2,070° F. engine test to be completed by the end of fiscal year 1982. This early ceramic effort at DDA has enabled us to achieve a head start on the technology that is crucial to the successful development of the 100-horsepower higher temperature automotive gas turbine. It has contributed to an expanded industrial base in ceramic material processing and fabrication technology that we are now drawing upon for gas turbine engine developments underway at both Garrett and DDA.

In 1979, the Lewis Research Center awarded parallel contracts to a DDA-Pontiac team and a Garrett-Ford team to develop the experimental engines that will demonstrate achievement of the technical objectives of the project I just mentioned. Figure 2 shows a model of the final version of the DDA engine, a 100-horsepower, two-shaft design, which is appropriate for incorporation in the X series of cars. With a silicon carbide turbine, this engine will have a turbine inlet temperature of 2,350° F. All parts for the test bed version of the engine are now on order, and we expect initial engine operation by the end of this fiscal year. Figure 3 shows a model of the final version of the Garrett engine, a 100-horsepower, single-shaft engine. With a silicon nitride turbine, this engine will have a turbine inlet temperature of 2,500° F. The test bed version of this engine, Figure 9, has been assembled and run. I believe some members of this subcommittee have had the opportunity to observe the tests. As you know, this engine has a metal combustor and a metal turbine but a ceramic regenerator. The current tests are to confirm that the engine design is suitable for substitution of ceramic components as they become available. We expect to have completed the initial test phase on this engine by the end of fiscal year 1982.

In the past year, DDA and Garrett have made significant progress toward developing ceramic components for the gas turbine engine. Material processes have been improved and required strength has been demonstrated in test samples of silicon carbide and silicon nitride [fig. 4]. The first set of trial ceramic parts for the DDA engine are shown. We believe these parts represent a significant advance in fabrication techniques for structural ceramic components. Following X-ray and other nondestructive evaluations, these parts will be subjected to cold pressure tests to verify their strength, followed later this year by hot rig testing. Hot rig testing of the ceramic regenerator and combustor is already underway.

Efforts to develop the ceramic turbine rotor [fig. 5], the most challenging of the ceramic components required for the engine, have progressed to overspeed tests of experimental rotors. These overspeed tests produce higher stresses than would be encountered in normal engine operation. At DDA, a silicon carbide bladed rotor was tested to 123 percent of design speed before failure, demonstrating strength in excess of the full speed requirement. You can see that this rotor fractured very uniformly, demonstrating uniform strength throughout the part, which is a significant technical achievement. The fractures actually run nearly circumferentially throughout the rotor.

Garrett and their major subcontractors for ceramic development have also made substantial progress in ceramic components [fig. 6]. The first set of trial ceramic parts has successfully completed nondestructive evaluation, and cold-pressure testing has started. Hot rig tests of the parts are expected to begin later this year. The critical part is, of course, the turbine rotor. It is silicon nitride for this engine. Garrett has cold spun a mass simulated silicon nitride turbine rotor [fig. 7] to 134 percent of design speed, demonstrating more than adequate bulk strength of the material. Subsequently, a bladed rotor of the same material has been tested to 115 percent of design speed before failure. We would like to see a greater safety margin for the turbine rotor, and Garrett will be continuing to improve the strength of the finished part.

Encouraging progress has been made by DDA and Garrett in advancing ceramic technology. Trial components have been fabricated to required dimensional accuracy using injection molding or slip casting techniques. These fabrication techniques are appropriate for mass production. However, much remains to be accomplished in developing ceramic technology for turbine engines. We must continue to improve the ceramic material and the forming techniques for making the parts so that the required strength can be consistently achieved in engine components. Furthermore, we need to demonstrate that the components, especially the turbine, can withstand cyclic temperature variations while retaining their strength for the required engine life of 3,500 hours.

As indicated earlier, in addition to advancing ceramic technology [fig. 8], substantial improvement in the aerodynamic efficiency of the engine compressor and turbine is also required. Compressor and turbine efficiencies near or above project targets have been measured in the rig tests at DDA in the past year. Let me say that the power turbine efficiency was targeted at 88.6 and has been measured at 90.5. The gasifier turbine efficiency, targeted for 84.2, has been measured at 82. Compression efficiency was targeted for 82 and has been measured at 79.6. Additional gains are required for the compressor and gasifier turbine; therefore, improved designs will be investigated later in the program. Similar progress in compressor and turbine efficiency has been made by Garrett.

Our progress in Stirling engine development [fig. 10] over the past year has also been significant. When Stirling engine development began at Mechanical Technology Inc. in 1977, the P–40, a heavy 53-horsepower engine used for research by United Stirling, a subcontractor, represented the best-available engine technology. In the past year, we completed steady-state testing of the first experimental Stirling engine designed with automobile requirements in mind. This 74-horsepower engine was tested at United Stirling. The engine was planned as an intermediate step in developing the Stirling engine for automotive use. It is heavier, at 10 pounds per horsepower, than needed for automotive use, uses a proven, but expensive, cobalt alloy for the heater head, and is limited to a peak temperature of 720° C. The engine has been tested for over 400 hours. The peak thermal efficiency is 37 percent, which is a significant improvement over the P–40 engine peak efficiency of 27 percent.

Based on measured efficiencies over the range of engine power, this experimental engine, if installed in a 3,300-pound car using gasoline, would be expected to provide a fuel economy advantage over current gasoline-fueled spark-ignition engines of 15 percent. We will be continuing engine testing this year to measure emissions and confirm engine control in transient operations typical of a driving cycle. In a parallel in-house effort, Lewis has used the engine test results to confirm the first nonproprietary Stirling engine performance code. This code will be published next month and will be available for general use.

Although Stirling engine technology has already been significantly advanced, a number of difficult technical challenges remain. To achieve the fuel-economy goal, the heater head operating temperature must be increased to 820° C. An inexpensive iron-based alloy must replace the present cobalt alloy. In the past year, Lewis has identified such an alloy. Tests of single heater tubes made of the alloy demonstrated the required strength. Figure 11 shows the laboratory apparatus at Lewis Research Center used for these tests. By raising the heater head to 820° C., employing new low-friction seals and other improvements, the goal of achieving a 30-percent fuel economy improvement over equivalent spark-ignition engines appears attainable.

Regarding the electric and hybrid vehicles, DOE's electric vehicle propulsion research is being performed by Lewis Research Center largely through university grants and contracts with industry. Test and evaluation of propulsion components and systems are performed in-house at Lewis using the road load simulator, a facility that can simulate a vehicle and typical driving requirements.

Electric propulsion research is focused on providing technology advances for both a.c. and d.c. propulsion systems. Because the battery provides a d.c. power output, almost all the electric cars in service today use d.c. propulsion systems. We, at NASA, believe a.c. propulsion systems can be competitive and perhaps superior, since a.c. motor technology has a large, domestic production base and the motor could be less costly than its d.c. equivalent. The technology advances we are seeking in both component and systems research are primarily directed toward reducing system weight, cost, and size to enable easier packaging. We are also seeking to improve the efficiency of the motor and its controller working together for the propulsion application.

As a part of our component research for d.c. propulsion systems in the past year, we have completed tests on two electronically commutated permanent magnet d.c. motors developed by AiResearch and VPI/Inland Motors [fig. 12]. In tests with their controllers, a combined efficiency of 90 percent was measured. This efficiency compares favorably with the combined efficiency of 85 percent for the d.c. motor and controller in ETV-1, the first car designed entirely for electric propulsion and built several years ago for DOE by the team of General Electric and Chrysler. In addition to the efficiency gain, the weight of each electronically commutated motor with its controller is 50 percent less than the weight of the ETV-1 motor and controller.

I would like to turn now to the progress we have made in developing a.c. propulsion systems [fig. 13]. In the past year, Lewis has tested an experimental a.c. propulsion system developed by the Eaton Corp. using the road load simulator test facility. This figure shows the Eaton system installed in the Lewis road load simulator. The Eaton system uses a conventional a.c. motor, an advanced controller of Eaton's design, and a unique two-speed shifting transaxle. It met all of its performance goals with an overall propulsion efficiency of 83 percent, a value equal to that measured for the ETV-1 d.c. propulsion system.

A contract has been signed with Eaton for a lighter weight and more efficient version of the system suitable for testing in a vehicle on a chassis dynamometer. Completion of tests of the improved system by Eaton is expected in fiscal year 1983. We have also initiated contract negotiations with Ford Motor Co. for a second advanced a.c. propulsion system that employs an innovative Ford concept to integrate the mechanical components in an arrangement that promises to further reduce system weight and cost. In addition, General Electric, a proposed subcontractor to Ford, is to provide an advanced power transistor that is expected to improve performance of the motor controller.

The Jet Propulsion Laboratory is also supporting DOE's electric and hybrid vehicle program by providing the technology for vehicle systems and on-board components such as the battery charger and state-of-charge indicator. The major activity at JPL in the past year has been the continuing development of an experimental hybrid vehicle [fig. 14]. The objective of this activity is to provide an evaluation of the potential of the hybrid vehicle using best available technology. The experimental hybrid vehicle uses an on/off spark ignition engine integrated with an electric motor driven by a small battery pack. In concept, the vehicle would operate as an electric vehicle in town and as a conventional vehicle on the highway.

General Electric, the prime contractor for the hybrid engine, is supported by Volkswagen, who is supplying the on/off spark ignition engine. In 1981, the hybrid power train was installed in an Audi 5000 test bed vehicle to confirm the operability——

Mr. **Dunn**. Dr. Kerrebrock, could I interrupt? Is this the engine that, as you pull up to a stoplight, actually shuts itself off?

Dr. **Kerrebrock**. Yes.

Mr. **Dunn**. If we could have a little bit further explanation of that, I think it is a terribly interesting concept.

Dr. **Kerrebrock**. Yes, sir; the basic idea is that you operate with the electric motor and the battery pack in urban driving, and then you revert to the piston engine for cruise on the highway and when the battery is low, of course, or for excess power.

Mr. **Dunn**. The conventional engine is used to recharge that electric battery similar to the concept of turbocharging in an engine, if I am also correct. Yes or no? Is it recharging that battery?

Dr. **Kerrebrock**. Yes; the engine does recharge the battery, but I think it can be recharged from an electric supply, too, so there is an option.

Mr. **Dunn**. Yes; but it negates the necessity of recharging every night.

Dr. **Kerrebrock**. Yes; it would depend on the duty cycle.

Mr. **Beattie**. The power blending at this point in time is still a matter of some study.

Mr. **Glickman**. Why don't you introduce your name for the record?

Mr. **Beattie**. Don Beattie from NASA. We are still examining how to handle the power blending and what the duty cycle would be for the engine and the battery. We could use the engine to charge the battery, but then that might not be the most efficient combination of the engine and the battery.

Mr. **Dunn**. Thank you.

Dr. Kerrebrock. Figure 14 shows the vehicle and its experimental powerplant. The effort was successful, and the car is now at JPL for additional performance testing. The hybrid test vehicle, the final vehicle of the development effort, will be delivered to JPL this year for complete evaluation testing including measurement of fuel economy and emissions. JPL is also supporting the electric vehicle project. Last year, JPL tested several lead-acid and nickel-iron batteries supplied by companies participating in the DOE battery research program.

Let me discuss vehicle systems and automotive alternative fuels. JPL and Lewis have been supporting DOE's highway vehicle systems project that was directed primarily toward evaluating industry-developed automotive hardware with the potential for near-term improvement in highway vehicle fuel economy. These efforts have been largely completed; no further efforts are planned. In the interest of time, I will not cover the past year's results of the activities NASA has managed in this project nor the results of our efforts for DOE in investigating synthetic fuels for automobiles.

I would like to say a word about heavy duty truck engines. At the beginning of this fiscal year, NASA initiated a new effort to significantly improve the fuel economy of heavy-duty diesel trucks by increasing peak component temperatures from 300 to 400° F. in current engines to perhaps as high as 1,400° F. To accomplish this, new engine materials such as ceramics will be needed, and small, very efficient gas turbines will be required to convert the higher temperatures in the exhaust system to additional shaft power for the truck's drive train. That is what we call a turbo-compound engine. Our major effort this year is to complete the initial planning phase for this effort.

Mr. Chairman, you expressed interest in NASA's future plans for supporting the Department of Energy's transportation program. The Department has testified as to its plans for the fiscal year 1983 budget request for this program. Based on that request, we plan largely to phase out of these activities in fiscal year 1983. NASA is aware of the congressional mandate for NASA to use its unique competence in support of automotive propulsion technology advances. I believe we have implemented that mandate. I believe that the support we would be willing to continue to provide to DOE if this program continues is in keeping with the mandate.

That closes my remarks.

Mr. Glickman. What you are saying by your last statement is that if Congress appropriates funds and mandates the continuation of these programs, you are going to proceed to continue the work that you have been doing in the past.

Dr. Kerrebrock. Yes, sir, there is an expanded answer to that in my written testimony which I can go through if you like.

Mr. Glickman. Well, why don't you go ahead because I will be curious as to what your role would be.

Dr. Kerrebrock. As presently planned, our support for these programs would phase out in fiscal year 1983, as I just indicated. As I mentioned, the major part of NASA's support to energy transportation is provided by Lewis. NASA will be reducing its civil service work force in fiscal year 1983. We must minimize the impact of work force reductions on our aeronautics and space roles.

Therefore, except for JPL, NASA will begin to phase out support of terrestrial energy research and development, such that by the end of fiscal year 1983, civil service manpower will be applied only to those energy programs yielding a strong benefit to our traditional aeronautics and space roles, or where continued NASA participation is essential to meeting commitments. Under these criteria, should DOE's transportation efforts be continued, NASA would expect to participate in the program. If you like, I could discuss under these groundrules our approach to these programs.

Mr. **Glickman**. Well, I think, on pages 12 and 13, you describe in greater detail what those are.

Dr. **Kerrebrock**. Yes, sir.

Mr. **Glickman**. I do not think it is necessary to repeat them. I just wanted to get that for the record.

Mr. Tribble, I would like to ask you, have you ever personally visited the Lewis Center?

Mr. **Tribble**. Yes.

Mr. **Glickman**. So, you have seen firsthand the heat engine programs?

Mr. **Tribble**. Yes.

Mr. **Glickman**. Have you also seen the electric vehicle programs?

Mr. **Tribble**. Yes.

Mr. **Glickman**. What about the Stirling engine program?

Mr. **Tribble**. Yes; I have seen them all. I have not visited MTI. I have seen the Stirling engine at NASA Lewis.

Mr. **Glickman**. Now, I would ask you a couple of things. Dr. Kerrebrock basically listed what I consider to be significant accomplishments made by NASA, DOE, and the contractors in these programs. Your testimony does not reflect, even though DOE has been funding these programs, a recognition of whether they have been successful or not, and yet, based upon what Dr. Kerrebrock has said, we have made enormous progress in certain areas, particularly in the ceramics area, in things that would not have otherwise been done. How do you respond to that, if you are going to cut them off?

Mr. **Tribble**. There is no question that great progress has been made in ceramics and in a number of other areas. My testimony was not intended to be interpreted as downplaying the significance of those accomplishments.

Actually, as I mentioned, the weight of the Stirling engine has been reduced by about 50 percent. Dr. Kerrebrock did point out the fact that these ceramic materials have been spun at their design levels. Now, of course, I believe I am correct in saying that all of these have been cold spun operations and, of course, there is a good bit of difference between spinning at design temperature and spinning at cold conditions.

But there is no question that there has been good progress. The two gas turbine concepts, the prototype will be available and tested on a dynamometer this year, and then to go on beyond the point where they will be at that time to improve efficiencies, it will be necessary to go to higher temperatures throughout the combustion and hot gas section of the engine.

As we have seen from this testimony today, the composition and the parts that are stationary have been developed with ceramics so that they are now producible. We would expect, as progress goes forth, first we need to hot spin the rotating components and determine what their characteristics of failure will be, see if they are in fact able to withstand that stress under those conditions. If they do, great. Then we are in a position to put those components into the engine with the components that are in fact stationary and begin to elevate the temperatures to the point where additional testing in the engine will be needed to ascertain the validity of that work.

The work would progress, then. Let us say that certainly we would expect to find some degradation at temperature of the ceramic parts. The next thing, then, would be to go back to the laboratory and determine what characteristics needed to be changed in order to come up with a ceramic material that would not degrade.

Mr. **GLICKMAN**. If I may stop you for a minute, that is all fine and good. If you zero the project out, though, who is going to be doing this?

Mr. **TRIBBLE**. We have some money in another program which will be doing ceramic research.

Mr. **GLICKMAN**. But, yesterday, the automotive people who testified, Ford and GM, said that ceramics work unrelated to engine development is not a terribly productive way of pursuing the enterprise. That is, doing ceramics work just to do ceramics work is not a very effective way of determining how it would work in an engine.

Now, what worries me is that Ford and GM have testified implicitly that they are laying off hundreds of thousands of people; they have got serious cash flow problems; they have got a lot of other near-term R. & D. efforts that they have got to pursue. It is unlikely that they will continue if government pulls out.

They also indicated, in connection with a question by Mr. Dunn, that they might be willing to up their cost share a bit more in order to see that the programs continue to operate.

I guess what worries me is that maybe what you are saying makes sense in abstract economic theory, but when we see the Japanese and the Germans moving ahead with significant programs, partly funded by their Governments, and we see our industry in the pits right now, I do not think it is going to be done without some continued Government involvement. I am very worried about this, and I just think that you and the Department of Energy really have an obligation to justify why you want to zero this out now.

Mr. **TRIBBLE**. Could I respond to that?

Mr. **GLICKMAN**. Sure.

Mr. **TRIBBLE**. Back to your original point that unrelated ceramic work, or ceramic work unrelated to the automobile, will not help the automobiles, we all have to agree with that. However, we see no limitation on the ceramic work that we do plan to do. We see no reason why that should not be related, too.

Mr. **GLICKMAN**. Which program would you be pulling that out of? Where would that be coming from?

Mr. **TRIBBLE**. In the energy conversion and utilization technologies, and that would be under materials development.

Mr. **GLICKMAN**. How much money have you allocated?

Mr. **TRIBBLE**. $3 million.

Mr. Glickman. $3 million?

Mr. Tribble. Yes.

Mr. Glickman. That is what you are proposing in fiscal 1983, then?

Mr. Tribble. That is right.

To carry this on further, we would contemplate that if the automotive companies would be willing to increase their cost share, and we would certainly welcome that, we could use their cost sharing in that they would be willing, then, to test additional components in the engines as they are produced. If first we could hot spin them, then we would want them to put those in the engine so that it would work in the environs in which it had to work.

Then, if there were problems with that, we would use the research and development money to try to eliminate those problems and, hopefully, come up with a different configuration, or a different material, or something that would be an improvement and then go back to them and have them try it again. It would be a developmental process, trying out a component, going back and seeing what the problems are.

Mr. Glickman. Have you talked with the industry people as to how they feel about your proposed fiscal 1983 budget? Have you talked with GM and Ford people?

Mr. Tribble. I have talked with them, and I know quite well how they feel about our 1983 budget. They think it is too small; there is no question about it. That is not unique to those people. I think you will find that most of the people that are participating in contracts that are financed by the Department of Energy are interested in seeing them go ahead.

Mr. Glickman. Yes; that is true. In addition, the automobile industry, directly and indirectly, employs several million people in the United States.

Mr. Tribble. Sure.

Mr. Glickman. Well, I am going to ask a few more questions. There are several statutes that you are obligated to fulfill, the Electric and Hybrid Vehicle Act, the Automotive Propulsion R. & D. Act, the Methane Research and Development Act, which does not require anything other than research.

At one time, there was talk that you were going to propose legislation to repeal the authorities contained in those acts. I have seen nothing like that, but how do you propose to relieve yourself of meeting your obligations under those laws without some sort of statutory change?

Mr. Tribble. We would hope that in due time there will be statutory relief. In the meantime, we would interpret—and this is our proposal—we propose not to spend any money on some of these aspects of the law. We certainly intend to comply with the law. We would expect that if you will agree with us and not allocate money for these purposes that we will be in a posture where we have your, at least, consent not to go forward with that activity, and that would be our proposal to you.

Mr. Glickman. I assume, however, that if we do not give you our consent, if we tell you to go ahead and spend the money and it is in a bill that the President ultimately signs, you will fullfil our mandate?

Mr. **Tribble**. We will do the best we can.

Mr. **Glickman**. Thank you. Mr. Dunn?

Mr. **Dunn**. Mr. Tribble, quoting from page 2 of your testimony——

Mr. **Glickman**. Excuse me, I am sorry but I am going to have to leave since I have another committee hearing. I appreciate your opportunity. Mr. Harkin will take over the chairing.

Mr. **Dunn**. Quoting from page 2, you say that the crisis conditions which existed in 1976 fortunately do not exist today. You say that prices of petroleum fuel have stabilized and our dependence on foreign crude is no longer increasing but, in fact, has diminished markedly. I agree with that, nevertheless I have a concern that we might be becoming lulled into a false sense of security in this country when we talk about decreasing reliance on foreign oil, because it still is somewhere in the range of 40 percent.

I had an opportunity in January to spend 3 days up in Canada meeting with Government, industry, and environmentalists and in my opinion Canada is much further down the road than we are in terms of a comprehensive program. They got together in 1975 and they established a nationwide goal that being to take Canada's reliance down from 25 to 10 percent. Everybody has a nitch in that goal; industry knows what it has to do; Government knows what it has to do; individuals know what they have to do, and they all agree and are still vigorously pursuing that goal despite declining oil prices.

My question to you is, and I have been as outspoken a critic of DOE as anybody on this committee, is that assuming for 1 minute that we agreed with the things that have been accomplished in these three engine programs and the fuel programs, and we agree that there is nothing more to be accomplished and that they should be zeroed out—assume for the minute that we agree with that—my question to you is: Where does DOE go from here? Where does this Government go from here in terms of helping out the automobile industry who is still the biggest user of oil? How do we get that reliance on foreign oil down? Do you have a substitute proposal for us?

Mr. **Tribble**. The work we are doing now on these engines, of course, would be helpful only in the outyears. I am sure that people who testified yesterday indicated that they were not thinking of putting this technology into an automobile in the near future, as a matter of fact——

Mr. **Dunn**. No; I am assuming for 1 minute that we agree with you. Let us assume that there is no more role for DOE in these three engines. My question to you is other than the $3 million that you just talked about in ceramics, what role do you see for DOE—or NASA—in the automobile industry? Is there a role in the future or is DOE taking the position that we have done all that we can do?

Mr. **Tribble**. One thing that the administration has done is to decontrol the price of oil which certainly has given the market clear signals as to what will be, what we will have to pay for our transportation. The results that are shown on the graph that I showed you indicate that the automobile industry is certainly responding to the public demand for increased economy. We would think that at this time, the Government could, yes, withdraw from this activity. There are, as I am sure you are aware, a number of other provisions, particularly in the 1981 tax law, that do give substantial benefits both for research and development and for rebuilding plant and equipment and it is the administration's posture that these would be helpful, not only to the automotive industry, but of course to all others. So, we would say that that is our substitute.

Mr. **Dunn**. What you are saying is that DOE has no other programs contemplated.

Mr. **Tribble**. Yes, that is right.

Mr. **Dunn**. Thank you.

Mr. **Harkin** [acting chairman]. Mr. Carney?

Mr. **Carney**. Thank you, Mr. Chairman. Mr. Tribble, do you see the U.S. automobile industry using the Stirling engine in the future?

Mr. **Tribble**. I certainly do not. I do not believe that any of the major automobile companies have given any indication that they would be thinking of such a thing.

Mr. **Carney**. Even if we did perfect it to a greater extent; increasing its efficiency; reducing its weight?

Mr. **Tribble**. They said that under those circumstances, they would consider it.

Mr. **Carney**. The automobile industry itself is not very keen on the engine?

Mr. **Tribble**. Certainly not.

Mr. **Carney**. Do you see a time in the next 10 or 20 years when there might be a sizable market among the general public for these electric engines? I know we are seeing an expanded market with fleet-type vehicles but do you see the general public going into electric vehicles as we presently know them?

Mr. **Tribble**. Not in the numbers that would attract the major manufacturers. I think that the electric vehicles may very well penetrate the market in fleet use and in organizations that can maintain a central charging and maintenance facility. The current problem is the cost here of the electric vehicles. There are many of us who have commuted for many years, let us say 10 or 15 miles one way, who could have been using an electrical vehicle and, in those instances, if the cost were comparable, then I can see that people will move into that but not on the scale that would be interesting to the major manufacturers; because of their assembly-line means of manufacturing, they are going to have to have relatively high volumes to justify getting into this and we would envision that hopefully the glider program which is a program whereby the major manufacturers produce the automobiles without the drive components and then let a smaller electrical vehicle organization put in the drive components, this is one approach of reducing the total cost of the vehicle and it is certainly a move in the direction to make it available to the public.

I do not know that I have really answered your question——

Mr. **Carney**. I think that you have. Of course, a speculative question is difficult to answer with certainty. I think the point that I am trying to make is that no matter how many millions we spend on engines like the electric motor and the Stirling engine, the "Big Three" are not going to get excited about it; we are not helping them. We hear about how much help they need. We are spending these monies and to me it seems that it is going away from the interests of the "Big Three" automobile manufacturers.

I do not see the problem for the automobile industry to be an engine as much as I see it to be years and years of neglect as far as retooling and our generosity in retooling our competitors, who are knocking our socks off right now from Germany and Japan, and of course Government action on some of the mandates; the restraints and emissions' requirements, that has not helped the industry either to come up with a motor overnight. I am not so sure that is going to answer the question. Do you have any idea of how much money we have spent on the programs that you have pointed out to be terminated to this point?

Mr. **Tribble**. We have that information. In the automotive gas turbine, through 1981, we have spent $101 million; in the Stirling engine we have spent $60 million; and in the heavy-duty transport technology we have spent $22.5 million.

Mr. **Carney**. Through 1981, Mr. Tribble?

Mr. **Tribble**. Yes.

Mr. **Carney**. So, $183.5 million. Do you think it was well spent?

Mr. **Tribble**. That is a tough one for me to evaluate, Mr. Carney.

Mr. **Carney**. I certainly can understand that. I will withdraw the question and I will yield back the balance of my time to the Chair.

Mr. **Harkin**. I do not see why it is an unfair question.

Mr. **Tribble**. I do not think it is an unfair question at all. It would involve my judgment to answer it and I came on board here about mid-May last year and there is a great deal that did transpire prior to that time that I am not acquainted with. I would have to look at the overall progress that has been made. Certainly, if we can—well, let me say this: one of the things that I think is important is the progress that has been made in ceramics. Ceramics, to me, has the opportunity to help us get along without some of the various costly and scarce metals and any developmental work that we can do in that area, I think will have benefit not just to the automotive industry but can be used in many other places. Certainly I do not believe that that money has been wasted.

Mr. **Harkin**. Mr. Tribble, starting on page 2 of your testimony, you said that the crisis conditions that existed in 1976 fortunately do not exist today; oil prices have been decontrolled and the price of natural gas has been permitted to rise to a more realistic level; prices for petroleum fuel have stabilized and our dependence upon foreign fuel is no longer increasing but, in fact, has diminished markedly.

I am sure that you have read this but I think it is interesting to read it again. Do you know who Sheik Yamani is?

Mr. **Tribble**. Yes.

Mr. **Harkin**. On January 31, 1981, at the University of Petroleum and Minerals in Dhahran, Saudi Arabia, he said the following:

> Saudi Arabia's interest may appear to be served by lower production rates and higher prices, irrespective of the outcome. Let me remind you of my earlier statements regarding the link between price and consumption rates. Whenever prices go down, consumption goes up, and vice versa. Whenever oil prices increase, large amounts of capital are invested in search of alternative sources of energy and in a

> search for oil in different areas. If we force Western countries to invest heavily in finding alternative sources of energy, they will. This would take no more than seven to ten years and would result in reducing dependence on oil as a source of energy to a point which will jeopardize Saudi Arabia's interest.
>
> As a result of the Saudi production and pricing policy, many major companies have been very reluctant to implement their energy substitution projects. This is in the interest of the Arab cause in that it restores the importance of oil.

What do you make of that statement?

Mr. **Tribble**. I think that is a very learned statement and I think it recognizes the ingenuity of the American free-enterprise system; that if they push us too far that we will find another way to do it and I am really pleased with that circumstance.

I do think that the prices that have increased as they have from, say 1972 until now, do provide ample incentive for all of us in all of the ways in which we consume energy to be more efficient. We are now looking at some data that I saw just recently that the average American spends on the order of 9 percent of his income for energy as compared to 6 percent back in 1972. This is incentive for the public to demand more efficiency on energy-consuming equipment. The automotive industry is responding and I think there will be a continued improvement in miles per gallon and in conservation generally.

Mr. **Harkin**. You do not see this as blackmail? What Sheik Yamani is saying is that we are going to price our oil at that price which the Western countries will not invest in alternative sources or in conservation. If we begin to invest heavily in conservation, they will reduce the price; if we do not, they will increase the price. They will increase the price to the point where they see us making a move and then they will stop. So, I think that your statement that the crisis is over is wrong. I think that the crisis has just begun. Prices may be stabilized now but when they want to increase the prices they will do so in the future. If it seems too much and we start to move in the directions stated, they will stabilize them again. I do not know to what level, but they will keep inching them up to the highest point they can. That is exactly what Sheik Yamani is saying and I think that what is happening now is that the policy that is being implemented in DOE is going to place us in a position by 1988 to 1990 where we were back in 1976. When they want to jack up those oil prices we are going to be sitting ducks because we will have no alternatives; we will not be able to go to alternative fuels.

I am going to take off on that and ask you some more questions but if you want to respond, please go ahead.

Mr. **Tribble**. Yes; I would like to. There is another side of the coin from the OPEC nations and even Saudi Arabia which is probably in the best position than any, because they, in view of their high rates of income, have built up substantial, domestic programs which are costing them billions and billions of dollars and with the decline in their ability to export oil and their prices that some concessions that they have made, I noted in an article not too long ago that there are now only three of the OPEC nations which are not net borrowers and, to me, this says that those countries that were depending on our continuing to finance their domestic programs are going to have to retrench, and they are in fact doing so.

Mr. **Harkin**. Perhaps slowing down might be better than retrench.

Mr. **Tribble**. That is right. Of course, you are aware that Saudi Arabia has, in fact, reduced its production on a number of occasions, perhaps very much in line with what Sheik Yamani has said. On the other hand, there is a limit below which they cannot drop their production and export and continue to support the programs that they have. And, we have in motion things within the United States that will make us continue to be less dependent on imported oil even if we do virtually nothing more.

Now, if you look at the graph there that you have, the lower line shows the efficiency of the U.S. fleet, and, of course, it is coming up much more slowly than the new automobiles because it is an averaging and has to take into effect the inefficiency of all the automobiles that are still on the road and that do get low mileage. On the other hand, as all those old gas guzzlers are replaced with the new ones, then this line, average fleet fuel economy, will continue to increase, which means that we will get more miles to the gallon; we will either be able to drive more or back away on consumption.

There are two or three other things that I think are militating in the same direction. Until the drilling of oil and gas wells was in a steep decline from 1955 until about 1980 when it flattened out. Now, in 1981, actually there were more rigs operating than there had ever been; production is turning the bottom of the curve and so we are going to have more domestic production. These are just some things that I felt I should mention because I feel as though they are actions and things that will help us in the years ahead.

Mr. **Harkin**. No doubt they will. Taking a look at your chart, you referred to, the new EPA fuel economy figures but really what we have to look at is average-fleet-fuel economy. What do you project for 1988 and 1990? What is that average-fleet-fuel economy going to be, because you are still going to have a lot of those gas guzzlers on the road, and I would submit to you that with continuing high interest rates and the economy being what it is, unless you have the faith that it is going to turn around, that more and more people will hang on to those old cars; they will do what they can to fix them up.

I can tell you case after case of my neighbors and myself not buying new cars but fixing up the old cars; keeping them on the road as long as possible. Detroit will tell you that.

Mr. **Tribble**. I am in that category. I am driving a 1971 automobile that is a real guzzler.

Mr. **Harkin**. What kind of car do you drive?

Mr. **Tribble**. It is a Cadillac.

Mr. **Harkin**. A 1971 Cadillac?

Mr. **Tribble**. That is right.

Mr. **Harkin**. Is that the car of the future?

Mr. **Tribble**. It certainly is not. [Laughter.]

It does about 10 miles to the gallon, but when you look at the economics of trading it and the interest rates you would have to pay on the differential, there is no choice but to drive it.

Mr. **Harkin**. That is what I am saying: This looks very good but you are talking about an average-fleet-fuel economy and I am saying that by 1988 and 1990 it is not going to be that high because of other factors. It is not going to be in the 25-mile range.

Mr. **Tribble**. I do not think it will be up there but it would certainly be up a great deal because this is going back to 1973 and, after all, there is a limit as to how long we are going to be able to keep these old gas guzzlers.

Mr. **Harkin**. Yes; but you have a 1971.

Mr. **Tribble**. And it has 100,000 miles on it and will not last forever.

Mr. **Carney**. That is less than 10,000 per year. That is not too bad; minimal driving almost.

If I might, Mr. Chairman, at this time—I am curious to know if we have any idea as to how much research and development the Federal Government, in dollars, spent on the internal combustion engine in the last 10 years?

Mr. **Tribble**. I am not aware of any expenditures in that area.

Mr. **Carney**. The internal combustion engine; the one that we are using in Detroit now; the one that has the significant increases that you showed us.

Mr. **Harkin**. Could you identify yourself?

Mr. **Stadler**. I am Henry Stadler, the director of the Vehicle Engine Research and Development Office.

Mr. **Carney**. The engines that have these enormous increases. How much money went into the research and development that produced these enormous increases? I mean, we have been spending money on a Stirling engine.

Mr. **Stadler**. Essentially, no money.

Mr. **Carney**. It is obvious to me that Detroit has had to make decisions, too. That is the point I was trying to bring out. I know that I took your time on that.

Mr. **Harkin**. What is your point?

Mr. **Carney**. My point is that we spent $180 million on engines that evidently Detroit does not have much interest in. Yet, Detroit, when we said you have to meet fuel economies—and it did not cost the Government a heck of a lot to do that; we told Detroit to meet fuel economies and they have responded.

Their research and development efforts, looking at this chart, seem to be much greater, much more efficient, and produce fuel savings better than the Federal research and development effort. That is what I wanted to bring out. I do not know, however, how much research and development we might have provided in the back years of the sixties or early seventies that produced that. But, if we did not, then that is graphic evidence that perhaps the automobile industry should keep up the good work and the Government should look very carefully at what we have been doing.

Mr. **Harkin**. I would point out again that this chart really looks good, but like some charts I saw on television last year; you really have to examine them closer——

Mr. **Tribble**. The difference is that these are historic and not projections.

Mr. **Harkin**. You estimate 25 miles new-car fuel economy as if that is really something great. It is certainly better than what we have had but it is nowhere near what we are going to need I think by 1988 to 1990.

You seem to be saying, and correct me if I am wrong, that we will never be needing any alternatives.

Mr. **Tribble**. I am sorry, I did not understand you.

Mr. **Harkin**. You seem to be saying that we will never have the need for any alternatives; that what we are doing now is plenty good because we are going to produce more oil and we have this new-car fuel economy and we will never need alternatives. Is that what you are saying?

Mr. **Tribble**. I would not want to go that far because——

Mr. **Harkin**. But, you do not think we need them now?

Mr. **Tribble**. I do not think we need the Stirling engine, particularly for automotive use. I think that the electric vehicle will be developed as it becomes economical. I think that the gas turbine may very well have a future because, if these high temperatures can be accommodated, it will produce an efficient engine. I do feel personally, and this is just my own judgment, that they will be first introduced to trucks, because I think that that is the most applicable location for them; long-haul trucks. From that beginning, they may very well develop to the point where they can be useful for automobiles but I do think that will take a while.

Mr. **Harkin**. I have a series of questions on the Stirling engine. In your testimony, you mention that the weight-to-horsepower ratio of the Stirling engine is approximately twice that of a conventional engine. Are you aware of the progress that has been made in this area during the past 2 years?

Mr. **Tribble**. Yes; it has been cut almost in half.

Mr. **Harkin**. What progress is projected for the next 2 years in a fully funded program?

Mr. **Tribble**. I have not heard any projections of late.

Mr. **Harkin**. My understanding is that it is expected to be reduced by yet another one-half, and that is quite remarkable, is it not; to reduce it by half. The program is on line and they project that they will cut it in half again in the next 2 years with a fully funded program.

Mr. **Tribble**. One of the factors in reducing it that first 50 percent was that prior to that time nobody had had any incentive to try to reduce the weight of a Stirling engine. They were satisfied with it being heavy.

Mr. **Harkin**. Well, it was for stationary purposes.

Mr. **Tribble**. So that first 50 percent was relatively easy to come by; I think that the next reduction will be a great deal more difficult.

Mr. **Harkin**. Dr. Kerrebrock, let me ask you. Did not NASA estimate that with a fully funded program, in the next 2 years this could be reduced by another one-half?

Dr. **Kerrebrock**. Yes, sir, that is a reasonable estimate.

Mr. **Harkin**. Well, that is reasonable, Mr. Tribble.

Mr. **Tribble**. I am sorry but I disagree.

Mr. **Harkin**. Why do you disagree? You have given me no proof of why you disagree.

Mr. **Tribble**. I think we have to take a look at the engine itself.

Mr. **Harkin**. Well, I have taken a lot of looks at it.

Mr. **Tribble**. I have too and I do not believe that we are going——

Mr. **Harkin**. Have you ever visited our prime contractor?

Mr. **Tribble**. Not MTI. I have seen the engine at NASA, Lewis.

Mr. **Harkin**. But you have not visited MTI to see what kind of progress they are making?

Mr. **Tribble**. That is right.

Mr. **Harkin**. They have met every goal, exceeded every goal, as a matter of fact. We see a lot of contracts from this Government where they do not meet their goals; they do not meet their objectives. Here is one that has.

I visited MTI a couple of years ago—have you ever been up there?

Mr. **Carney**. I have driven the car. In fact, I drove it over in the Swedish lab, so I have seen it.

Mr. **Harkin**. Has not the power to weight ratio of engines gotten worse in recent years with the addition of environmental controls?

Mr. **Tribble**. No question about it.

Mr. **Harkin**. O.K. What we see in this graph really represents more of a downsizing of cars rather than something internal in the engine. If you build smaller engines and smaller cars, you get more economy. But, in the engine itself, we are seeing that the power to weight ratio in conventional engines is increasing.

As you know, with a Stirling engine, it meets all environmental standards. You do not need a muffler or exhaust system. You do not need all of those pollution control devices, and therefore you have that little bit of weight reduction to work with, aside from the fact that NASA has projected that they can reduce it by another 50 percent.

Mr. **Tribble**. Mr. Chairman, may I make one statement. You were not in the room when we discussed this chart initially and I mentioned that there is some information on the typewritten sheet that accompanies it. I would draw your attention to the last bullet at the bottom of the page.

You would normally think that most of this progress is because of downsizing, but this study at Oak Ridge National Laboratory has indicated that that is not the case and the last sentence there points out the fact. They say,

> The important factor contributing to increased fuel efficiency in the last two years has been technological improvement, comprising 65% of the improvement made from 1969-1980, and 75% between 1980-1981.

Mr. **Harkin**. Are you talking about fleet average or individual cars? That is the key right there.

Mr. **Tribble**. Fleet average. No, this would be new automobile.

Mr. **Carney**. It cannot be fleet; it has got to be——

Mr. **Harkin**. It says,

> Total improvement in U.S. fleet miles per gallon made between 1979 and 1980, only 14% is due to shift to smaller classes of vehicles.

I would agree totally that that is true if you are talking about the fleet. I am talking about those individual cars that are being made. That is a key sentence there.

I think you have some apples and oranges, if I can use that old phrase, mixed in there.

Mr. TRIBBLE. It was certainly my impression from the presentation that I got this, that we were talking in terms of the new car economy.

Mr. HARKIN. I would not stake my life on it, but I would stake quite a bit that what they are saying there has got to do with fleet average because the next sentence says that "from 1980 to 1981 this figure is even smaller; a mere 4%." What they are talking about is the U.S. fleet miles per gallon.

Mr. TRIBBLE. I would certainly like to check that and let you know.

Mr. HARKIN. Would you please because I would like to know.

[The information follows:]

The Oak Ridge National Laboratory (ORNL) analysis refers to new cars in model years 1980 and 1981. This is shown clearly in the attached table. From this table it can be seen where the "75 percent technological improvement in 1980-1981" came from. It is the sum of "all autos becoming more efficient" (53 percent) and "adding and dropping models" (22 percent).

One of the most important factors in making all autos more efficient was the downsizing (keeping the same interior volume but reducing exterior dimensions and weight) that was performed in every auto size class. For example, in 1981 domestic compact autos weighed about 30 percent less than in 1980.

The "technology" improvements identified by ORNL also include other factors such as shifts to smaller engines, aerodynamic improvements, and other factors. Their precise contributions have not yet been quantified.

DETERMINANTS OF IMPROVEMENTS IN NEW AUTO FUEL ECONOMY

	Model year 1980	Model year 1981
Change in miles—per gallon from previous model year	2.5	2.4
Percent of change due to:		
All autos becoming more efficient	53	53
Shifts to more efficient autos within same size class	21	21
Adding and dropping models	12	22
Shifts to autos in other size classes	14	4

Source: "Motor Vehicle quarterly MPG and Market Share Newsletter," Oak Ridge National Laboratory, Oak Ridge, Tenn., October 1981.

Mr. CARNEY. I have an unfortunate situation where I have to go downstairs at 11:30 a.m. I have a couple of questions about that Stirling engine, if I may, Mr. Chairman.

Mr. HARKIN. Sure, go ahead.

Mr. CARNEY. I was wondering, with the Stirling engine we have found significant reductions in the weight of the engine. Was that due to the fact that we are using the types of metal that could, perhaps, become a problem in the United States because we do not have the alloys necessary to make those metals.

Mr. TRIBBLE. I would not think that the substantial reduction in weight would be from the components that required the high-alloy metals. The high-alloy metals are required largely in the heater head and in the high-temperature sections and they are relatively light in comparison with the block and other, more massive, components of the engine. So, I would think that the reduction that did take place would have been primarily in the plain carbon steel end of the machine, but I would like you to ask that question of some of the people here who are a great deal more knowledgeable than I am.

Mr. **Carney**. Dr. Kerrebrock, would you like to respond to that?

Dr. **Kerrebrock**. The weight of any device like this is, of course, related to design. If there is no incentive to reduce the weight, as was the case for the engines that were built previously, there is a lot of weight that can be taken out simply by more careful design of each of the parts. But, that is only part of it. The other thing that we are talking about is the horsepower/weight ratio of the engine. This ratio is sensitive to a number of factors such as the operating speed, temperature, displacement, frictional losses, and auxiliary power needs for components such as the combustor air fan. The improvements in horsepower-to-weight ratio of the Stirling engine has been achieved by optimizing these factors, using current technology for a peak temperature of 720° C.

Mr. **Harkin**. I am sorry, I did not hear that, doctor.

Dr. **Kerrebrock**. I said that the horsepower of the Stirling engine is related to a number of factors including the speed of rotation. If you want more power-to-weight ratio you can improve the design until you come up against some technological limit.

Mr. **Carney**. I have 2 seconds and then I have to run. I have questions for both of you. Simply, did you say, either of you, that you cannot apply the ceramic techniques to the Stirling engine as readily as you could to the other types of engines, or perhaps, not even at all?

Mr. **Tribble**. You could not apply it to the pressure parts. The statement you made, yes, is essentially true. Certainly there are some parts of the Stirling engine where ceramics could be used. It would not be as adaptable as it would for a gas turbine engine.

Dr. **Kerrebrock**. I would say that the critical high-temperature part in the Stirling engine is the heater head—the heat exchanger that changes heat between the combustion chamber and the working fluid. This is a part that requires a very fine structure and it has a very high level of thermal stresses due to the heat transfer; both things are difficult to accommodate with ceramics. So, it is a very difficult application for ceramics and our view at this time is that the most appropriate material there is an alloy.

Mr. **Carney**. I appreciate that the chairman is being very patient with me. One last question: In that Stirling engine, is it necessary to use the types of alloy that could, in the future, become difficult to obtain?

Dr. **Kerrebrock**. We have made significant progress in our research program just in the last year in developing low-cost, iron-based alloys that will meet the requirements. We are not quite there yet.

Mr. **Carney**. I thank you very much. Mr. Chairman, I certainly thank you for your patience with me and I only apologize for having to leave for another meeting.

Mr. **Harkin**. No problem. I would just follow up on a question of yours. Ceramics are not really necessary for a Stirling; you are not operating at those high temperatures as in the turbine. Really, were they not just looking at ceramics more for cost and weight, but not really for the efficiency of the engine itself? Is that not true?

Mr. **Tribble**. You do need the high temperatures in the Stirling engine, too.

Mr. **Harkin**. But not anything near what you are talking about for the turbine?

Mr. **Tribble**. You do need the high temperatures in the Stirling engine, I am sorry.

Mr. **Harkin**. Yes, you do need high temperatures in the Stirling, obviously the higher the temperature the better the efficiency, but again, we are talking about a range. Obviously you are looking at the optimum.

Mr. **Tribble**. We are looking in the gas turbine engine at a range of trying to get between 2,350 and 2,500° F., but we are having to use metals in the Stirling engine that have an upper range on the order of 1,500 degrees. Is that not right?

Dr. **Kerrebrock**. Yes, 820° C. which is the same.

Mr. **Harkin**. So, it is less?

Mr. **Tribble**. Yes.

Mr. **Harkin**. In your testimony you seem to home in on the upper design limits of pressure and temperature. Let me get your testimony here. You say that the Stirling engine depends upon the use of hydrogen or helium at pressures in excess of 1,000 pounds per square inch; it also depends upon the temperatures that are at the upper limits of presently available metals. Cannot the Stirling engine operate over a wide range of temperatures and, of course, be designed to operate at various temperatures? It does not have to operate at the optimum, but it can operate over a range of different temperatures?

Mr. **Tribble**. You will not get any substantial improvement in efficiency of a Stirling engine unless you can go to the high temperatures.

Mr. **Harkin**. OK. You will get more efficiency?

Mr. **Tribble**. Yes.

Mr. **Harkin**. Dr. Kerrebrock said: "Based on major efficiencies over the range of engine power, the first experimental engine, installed in a 3,300 pound car, using gasoline, but provided a fuel economy advantage of 15 percent over the current internal combustion engine." That is just using the Mod I engine. We can go on from there and work on efficiencies toward those upper limits, but even taking this we are ahead of the game, right?

Mr. **Tribble**. I think this first one—what were the temperature limits in your heater head on this one? I think they were already up pretty well to the limits of the materials.

Mr. **Carney**. What were they? Do you know, Dr. Kerrebrock?

Dr. **Savitz**. 720 degrees.

Mr. **Tribble**. 720° C., which is only 80 degrees below what he is talking about reaching.

Mr. **Harkin**. No; I think he is talking about 850 degrees, which is 130 ° C. more.

Dr. **Kerrebrock**. The numbers we are quoting 720° C. and a thermal efficiency of 37 percent for the current engine. What we said is that we would like 820° C. in order to achieve the fuel consumption target of the program. I do not happen to have the efficiency associated with that at my fingertips.

Mr. **Harkin**. Mr. Tribble, you mentioned expensive alloys using comparatively scarce materials that are required. However, we have had a major materials effort going on in conjunction with the Stirling engine program. Are you aware of the results of this?

Mr. **TRIBBLE**. Yes; I am aware of that. We now have metals that no longer require cobalt, but I am under the impression that they continue to require chrome. Is that true?

Dr. **KERREBROCK**. Yes; I think that is correct.

Mr. **TRIBBLE**. Of course, chrome comes from either Zimbabwe or Russia.

Mr. **HARKIN**. And it says in your testimony, Dr. Kerrebrock: "to achieve the fuel economy goal, the heater head operating temperature must be increased to 820° C. using an inexpensive iron-based alloy rather than the present cobalt alloy. In the past year Lewis has identified such an alloy." What is that alloy?

Dr. **KERREBROCK**. I believe that it is an iron-based stainless steel which does contain considerable chromium, as do all stainless steels—chromium and nickel. The essential point there is that the Lewis Research Center developed a technique for reducing the hydrogen permeability of the alloy by treating the work-cycle gas hydrogen, with carbon dioxide. That is an invention that could not have been programed.

Mr. **HARKIN**. Next, you say that the Stirling engine is entirely different from an internal combustion engine. You say you have seen an engine?

Mr. **TRIBBLE**. Yes.

Mr. **HARKIN**. You know what the crosssection of it looks like, you know how it operates. It has pistons, gears, crankshaft, crankcase. Is it not just a little bit of an exaggeration to say that it is entirely different? It is somewhat different but you still have pistons and that sort of thing. Of course, you do not have a distributor and things like that, but the pistons go up and down and turn the crankshaft and the transmission. So, it is different, but to say that it is entirely different is not quite on the mark.

Mr. **TRIBBLE**. Mr. Chairman, I believe that if you drove an automobile with a Stirling engine into any automobile repair shop in the country, the best mechanic in there would look at that and say: "My gosh, I have never seen anything like that before," and he would not be able to begin to repair it.

Mr. **HARKIN**. I have no doubt that you are absolutely right, but it is not entirely different.

Mr. **TRIBBLE**. Well, I will have to say that it has reciprocating parts in the gear.

Mr. **HARKIN**. What you are saying is, of course, is that it will take a change in the infrastructure, but we know that. Is that not true of a turbine? What if you drove a turbine car in there? What would they say?

Mr. **TRIBBLE**. There is a great deal more experience with turbines because gas turbines are in substantial present use, as in jet engines, as peaking units for powerplants, and so there is not a great deal of difference between the—as a matter of fact——

Mr. **HARKIN**. I am not going to drive my car into a powerplant. I will drive it into a gas station.

Mr. **TRIBBLE**. Of course not, but you already have the mechanics that are familiar with the gas turbines; that is my point.

Mr. **Harkin**. Well, I would tend to disagree with that a little bit. There may be some who have been involved with them in the Air Force, or Navy, or whatever, but it is a drop in the bucket compared to the amount that will be needed.

I just think that the Stirling engine is not all that different. It is different, I will grant you that, but to say it is entirely different I think gives it an attribute that it does not have.

I am quite concerned, as you can gather by now from my line of questioning, about what you are doing to the Stirling engine. I am like Mr. Carney. I have followed the development since I first came on this committee in 1975. I talked with people at Ford as to why they gave up their contract. I think they made a terrible mistake at that time. Perhaps if you could look into their mind or heart of hearts they might say that, too. I do not know. I know what the Japanese are doing. I do not say that we should always do what the Japanese are doing, but when they are committing something in the order of 10 billion yen over the next 10 years, which is not that much money, but it indicates that they are moving ahead rapidly; and that is what we know they are doing. I do not know what else they may be doing with the Stirling engine that we do not have knowledge of. We have made tremendous progress with the Stirling in 3 years to reduce the weight and we have increased the operating efficiency.

I am like Mr. Carney, I drove the first engine and the second engine, with the ability to use alternative fuels. I drove the car where you can go from unleaded gasoline, to gasoline, to diesel fuel, to alcohol, to jet fuel. You can drive the car down the road and switch the fuel and you keep going.

The progress that we have made in the Stirling engine has been nothing short of remarkable and to drop it now, I think, is just cutting off our noses to spite our faces. I think it is pennywise and poundfoolish.

Mr. **Tribble**. Mr. Chairman, I appreciate your point of view and I have another one that I would like to make here because I feel like you and the committee should have the benefit of all the information that we can gather on this subject. Here is a publication dated January 1, 1982, Wards Engine Update and there is an article here that is entitled, "GM Evaluates Powertrain Outlook Through 1990." One of the bullets in this article is: "Stirling engines for passenger cars are dead—deposed as GM puts it" and I really think that that says a great deal. These folks, as you may know, years ago spent millions of dollars on the Stirling engine and abandoned the project and they do not feel that it has value.

Mr. **Harkin**. Mr. Shamansky?

Mr. **Shamansky**. Thank you, Mr. Chairman. Mr. Secretary, I do not have the benefit of any biographical information on you, other than your office, so I am having trouble understanding your basic premises here with respect to the role of the Department of Energy. Let me ask some general questions?

Mr. **Tribble**. Surely.

Mr. **Shamansky**. You are an appointee of the Reagan administration?

Mr. **Tribble**. That is right.

Mr. **Shamansky**. Were you aware that, when you took the job, that one of the planks in the platform was to get rid of the Department of Energy?

Mr. **Tribble**. Yes.

Mr. **Shamansky**. In a sense, you came on board to dispose of the Department of Energy?

Mr. **Tribble**. I came on board to do whatever President Reagan thinks we should do.

Mr. **Shamansky**. Which is to get rid of the Department of Energy.

Mr. **Tribble**. Yes, sir.

Mr. **Shamansky**. Do you support the Clinch River breeder reactor?

Mr. **Tribble**. That is not in my area.

Mr. **Shamansky**. Well, do you support it?

Mr. **Tribble**. Yes; if the President supports it, I support it.

Mr. **Shamansky**. And he is supporting it. This committee got rid of it but they put it back in and you think that is good technology because the President thinks that, therefore you think that.

Mr. **Tribble**. I think he is getting good advice and I am willing to stand on it.

Mr. **Shamansky**. And that good advice is to have the Clinch River breeder reactor. How do you feel about the Barnwell, South Carolina, reprocessing plant that the Secretary of Energy likes so much?

Mr. **Tribble**. I will have to give the same answer to that. I am not acquainted with that facility and I do not know what it is designed to do. I have no knowledge of my own which relates to it.

Mr. **Shamansky**. But, whatever they do, it is all right by you?

Mr. **Tribble**. Yes.

Mr. **Shamansky**. Now, on page 2 of your prepared statement, you refer to the fact that the prices for petroleum fuel have stabilized and our dependence upon foreign crude is no longer increasing but, in fact, has diminished markedly.

Mr. **Tribble**. Yes.

Mr. **Shamansky**. And, as far as you are able to forecast in the future, you anticipate that to be the case? Right?

Mr. **Tribble**. I think the general projections that I read, and I am certainly no person who has the capability of projecting this, but the consensus seems to be that we will have declining import demand for several years.

Mr. **Shamansky**. For several years? And how many are several and what happens after that?

Mr. **Tribble**. Of course, during this same period of time, domestic production is increasing——

Mr. **Shamansky**. Excuse me, are you suggesting that overall the domestic production is meeting our need?

Mr. **Tribble**. No.

Mr. **Shamansky**. OK. So we do have a foreign dependence? Correct?

Mr. **Tribble**. Yes.

Mr. **Shamansky**. OK. Regardless of the increase in domestic production, we are still dependent upon OPEC, correct?

Mr. **Tribble**. Yes.

Mr. **Shamansky**. OK. Go ahead. I just want to know what your basic premises are. We have this rosy picture, that we have got this thing licked is what you are telling me.

Mr. **Tribble**. Some of the other factors that I think should be helpful along that way are that the conservation measures that are being taken will continue to have beneficial results.

Mr. **Shamansky**. Which ones?

Mr. **Tribble**. Those that are being implemented in new buildings, for example, where they are being built to higher energy efficiency standards.

Mr. **Shamansky**. And they are using the gasoline?

Mr. **Tribble**. No.

Mr. **Shamansky**. I am talking about gasoline, about automobiles right now.

Mr. **Tribble**. Refineries are quite capable of switching from fuel oil to gasoline with the same barrel of crude so that if a building can cut back on the use of No. 2 oil and the refinery can change its mix and produce more gasoline, this does help.

Mr. **Shamansky**. As an investor in real estate my investment goes over 30, 40, or 50 years, correct? And you are saying that that is going to significantly reduce our dependence upon OPEC oil? Is that your strategy?

Mr. **Tribble**. I am saying that this is one factor.

Mr. **Shamansky**. I see; a significant factor.

Mr. **Tribble**. Yes. Over time.

Mr. **Shamansky**. Yes, over time. But let us deal in the short-range, the next 4 or 5 years.

Mr. **Tribble**. In the short-range, I think that the more efficient automobiles that are coming on will be a factor and I think that the price structure that now exists is going to give continuing incentive for the producers to increase production.

Mr. **Shamansky**. But the price factor, you are telling us, is going down.

Mr. **Tribble**. Yes.

Mr. **Shamansky**. So, it will not be an incentive.

Mr. **Tribble**. It still is an incentive.

Mr. **Shamansky**. OK. Mr. Tribble, I tell you what. I do not want to toy with you. It is an insult to you and it does not do any credit to me. I find your testimony incredible. I am upset by it and I think it provides me no guidance. You are basically, as far as I am concerned, a fox in charge of the hen house. The margin that we had when Iran was taken out of production shot the gasoline prices to almost double, the reason being that we have very narrow margins.

I am very much aware that the Reagan administration promised a recovery, but in fact delivered a recession. And, that recession has a lot to do with the amount of gasoline we are using and importing and had we had a recovery, which we will have eventually in spite of the administration, we will then be right back where we were needing significantly new types of technology. The automobile industries in the United States have demonstrably proven that they cannot handle it. Unfortunately, we were the last source; we are the last recourse.

I really regret that you came in to do away with this program because to me it frankly makes your credibility difficult to accept and I do not want to waste any more of your time on it.

Mr. **Tribble**. I am sorry that you have such a low opinion of me.

Mr. **Shamansky**. I am talking about your basic premises. So far, it is a singularly short-sighted analysis; you are completely ignoring why our consumption is down, and if we have a world-wide recovery, we are going to be right back in the soup. Science and technology, sir, are a continuum. We do not stop here and just automatically pick up 5 and 10 years later having not missed anything.

The chairman pointed out that the Germans are going ahead; we are not even talking about what the Japanese are doing. Volkswagen hopes to have a 70 and 90 mile per gallon range, depending on gasoline or diesel. We want to do something in this country and all you are saying is that the magical market forces will take over as they have this past year, and look what a terrific spot we are in with the magical market forces.

I find it very unconvincing and I feel an obligation to be blunt with you about it. Thank you.

Mr. **Harkin**. There are just a couple of things I wanted to ask you about.

It seems to me that in your testimony, you seem to be leaning more toward the gas turbine than the Stirling. In other words, you seem to indicate, Mr. Tribble, that we have got to push ahead more with the gas turbine and just drop the Stirling. Is that a fair statement?

Mr. **Tribble**. I think so. There is certainly a promise for the high temperature gas turbine and I honestly do not see one for the Stirling.

Mr. **Harkin**. It is my information that it is too early to make any such decision and that the data is not there to support one over the other. I would be interested in what hard data you have, aside from just your own innate feelings perhaps, but what hard data you might have that you could outline to this subcommittee, to indicate why you feel that way. Am I making myself clear?

Mr. **Tribble**. Yes; I understand what you mean. I do not know what hard data that might be but I would have to say that the gas turbine concept is quite widely used, as I mentioned, in the Department of Defense; the turbochargers for diesels—it is a centrifugal device, air compressors now, many of them are centrifugal three-stage, high-rpm devices, up say 10,000 to 12,000 r.p.m. so that the technology for this kind of engine is more widely used at the present time and I just feel that the impetus that it has will bring in the gas turbine. The gas turbine has the same advantage over the Stirling that the steam turbine has over the steam engine, in that it is a revolving device rather than reciprocating. It has many fewer moving parts and is just simply a simpler engine to build and maintain and those are the reasons that I feel that the gas turbine will preempt, will be able to move forward.

Mr. **Harkin**. OK. I understand that. I just wonder about all of the other data though: the performance data; the cost data; the technological problems that we still have to overcome in both, and, when you add them all up how does it come out? I understand what you are saying.

Maybe I could ask Dr. Kerrebrock to comment on that, if you want to. Do we have sufficient data points to indicate that the Stirling engine, at this time, ought to be dropped in favor of the gas turbine? I do not know if that is a fair question, maybe it is not.

Dr. **Kerrebrock**. I will be happy to comment. I think we ought to recognize at the outset that either of these alternative engines will have a very difficult job penetrating the market in competition with the conventional Ottocycle and diesel engines which are well established and in which there is a very deep and broad infrastructure for manufacturing techniques and maintenance. And, something else which should not be neglected is the fuel-supply situation which is well established for those other two.

If you were to ask me which—the gas turbine or the Stirling engine—is most likely to penetrate the market in automobiles, my answer would probably be the gas turbine. I make that judgment on the basis of my technical understanding of the two of them. It really is a matter of producibility. The fact is that the Stirling engine, as we presently conceive it, is a high-cost device. The technology is costly to produce and we do not know whether volume production would bring the cost down. It might. I certainly would not say that it cannot. But, at the present time, the technology is costly relative to the existing engines. The same thing is true of the gas turbine, and then it is a question of judgment on which reasonably technically informed people may disagree as to which one is the most likely to succeed.

The questions are different for the two.

Mr. **Harkin**. One last thing, I know we have to break and I do not want to prolong it, but the chrome issue. Could you develop that more for me, Dr. Kerrebrock?

Dr. **Kerrebrock**. Which issue?

Mr. **Harkin**. The issue of the chrome alloy. I want to know, for example, projecting ahead, if we were to shift substantially to manufacturing Stirling engines, what kind of chromium requirements are we talking about? How about substitutes? Is there a possibility of substitutes; technical changes that would substitute something else for the chrome?

Dr. **Kerrebrock**. My judgment is that if an iron-based chrome-nickel alloy can be developed which is satisfactory for the heater head, then the material supply problem is not a significant one. After all, we produce millions of pounds of stainless steel in the United States every year. It is true we do import the chromium; but, we import it in very large amounts. For example, the catalytic converter on almost everybody's automobile is made out of stainless steel which has a high chromium content.

Mr. **Harkin**. Mr. Shamansky?

Mr. **Shamansky**. Thank you, Mr. Chairman. Dr. Kerrebrock, if I may ask you a few questions. If you know, can you inform us as to the status of research in Western Europe and Japan in these areas? Does it exist and what is its status? What prognosis do you have for it?

Dr. **Kerrebrock**. Yes, sir; I do not have a detailed knowledge but what I can say is this. The Japanese have earmarked the development of high-performance structural ceramics, silicon nitride, and silicon carbide as a major effort. They have committed to the production of such ceramics and the development of the infrastructure for producing them. For example, they have supplied for free, parts to Garrett for testing in engines. It has been announced recently that they have fabricated a ceramic piston engine which runs at elevated temperatures. I have no more detailed knowledge on that other than it does seem to run.

Mr. **SHAMANSKY**. Is it your conclusion that they are doing this kind of work with a view toward a gas turbine engine or, perhaps, a Stirling engine?

Dr. **KERREBROCK**. I believe that their commitment is based on the possibility of replacing the high-temperature parts in many heat engines with ceramics. There are many parts which would benefit from that.

Mr. **SHAMANSKY**. And you would characterize this as a Japanese industry/Government cooperative approach?

Dr. **KERREBROCK**. Yes, sir.

Mr. **SHAMANSKY**. So, there is a role for the Federal Government in that.

Dr. **KERREBROCK**. There are also initiatives in Western Europe. Daimler-Benz is working on the gas turbine and I understand there is also involvement in the Stirling engine.

Mr. **SHAMANSKY**. Do you have any information as to whether or not the Federal Republic of Germany has any role in that development?

Dr. **KERREBROCK**. No, sir, I do not, but perhaps Mr. Beattie knows.

Mr. **BEATTIE**. They do. There is a joint program.

Mr. **SHAMANSKY**. So, it would be different, on that basis alone, it seems to me, than what is indicated by Mr. Tribble here. That is my conclusion. I am not asking you to comment on that.

Based on what your studies have shown so far, do you have any idea where you think our research can go within the next few years?

Dr. **KERREBROCK**. It is my view that in order for either of these two alternative engines to actually penetrate the market, a very large involvement of the manufacturers is necessary. The Federal Government has an essential role in what we would call the basic research and technology which I doubt that the private sector will find possible to provide.

Mr. **SHAMANSKY**. Have you seen so far a significant participation or willingness of the private sector to pick up this research in case the Federal Government drops it?

Dr. **KERREBROCK**. I have not yet.

Mr. **SHAMANSKY**. You have not noticed any. I have not either. Mr. Tribble, have you noticed any such willingness on the part of the private sector to pick this up, independently of the role of the Federal Government?

Mr. **TRIBBLE**. No; I have not. I understand that they are not even willing to cost share at a very low cost.

Mr. **SHAMANSKY**. Thank you very much. It is now just before 12. Thank you for your participation. The committee stands in recess.

[Whereupon the subcommittee recessed at 11:59 a.m.]

[The prepared statement of Dr. Kerrebrock follows:]

HOLD FOR RELEASE UNTIL
PRESENTED BY WITNESS
MARCH 3, 1982

STATEMENT
of
Dr. Jack L. Kerrebrock
Associate Administrator for
Aeronautics and Space Technology

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

before the

Subcommittee on Transportation, Aviation and Materials
Committee on Science and Technology
House of Representatives

Mr. Chairman and Members of the Subcommittee:

It is a pleasure for me to appear before you today to discuss progress in the automotive research projects NASA is managing for the Department of Energy (DOE). As you know, except for the electric and hybrid vehicle systems technology and a few other minor activities at the Jet Propulsion Laboratory (JPL), the Lewis Research Center (Lewis) has the major responsibilities for this work. Significant progress has been made by Lewis in the past year in the gas turbine and Stirling engine projects, and at JPL, we are approaching an important technology benchmark in hybrid vehicle development. Today, I will review the progress in these projects and others we are supporting for the Department of Energy, and will briefly discuss our future plans.

HEAT ENGINES

The technical objectives of the automotive gas turbine and Stirling engine projects are to provide the technology for a 30% improvement in fuel economy over equivalent spark ignition engines, emissions below Federal research goals, and multi-fuel capability. For the gas turbine to meet the fuel economy objective, the engine must be capable of operating at temperatures from 2350°F to 2500°F. This will require the development of uncooled ceramic components. In addition, compressor and turbine aerodynamic efficiencies must be advanced beyond those previously obtained in small turbine engines.

Development of ceramic component technology in support of the gas turbine project began in 1976 with the award of a contract to Detroit Diesel Allison (DDA) to improve ceramic properties, to advance the understanding of structural design techniques for brittle materials and to fabricate components for testing in an existing 300-HP turbine engine. In the past year, DDA has continued its efforts to fabricate and qualify in test rigs the components needed for an engine test at 2070°F turbine inlet temperature. Figure 1 shows these components. Each has been successfully tested in component test rigs to confirm its suitability for engine use, except for the turbine inlet plenum that failed. Review of the test data revealed that the plenum failed due to unexpectedly high thermal gradients in the rig that exceeded those expected in the engine. The rig is being modified to reduce the thermal gradients. The plenum will be retested to confirm that the design is satisfactory. Once this is accomplished, DDA also plans to test the components in the engine to confirm that the fabrication processes and design methods are satisfactory. This early ceramic effort at DDA, to be completed by the end of FY 1982, enabled a head start on the technology that is crucial to the successful development of the 100 HP higher temperature automotive gas turbine. Particularly, the effort has significantly contributed to an expanded industry base in ceramic material processing and fabrication technology which we are now drawing upon for gas turbine engine developments underway at Garrett and DDA.

In 1979, Lewis awarded parallel contracts to a DDA-Pontiac team and Garrett teamed with Ford to develop the experimental engines. Figure 2 shows the DDA engine, a two-shaft, 100-HP model designed to run at 86,000 RPM with a turbine inlet temperature of 2350°F. Figure 3 shows the Garrett-Ford engine, a single-shaft, 100-HP model designed to run at 100,000 RPM with a turbine inlet temperature of 2500°F.

The differences between the DDA and Garrett-Ford engine designs are significant, particularly in regard to the ceramic material advances required for the turbine rotor. The larger turbine and higher engine speed inherent in the Garrett-Ford single-shaft engine requires development of ceramic materials with greater strength than that needed for the DDA two-shaft, two turbine engine. On the other hand, the relative simplicity of the single-shaft design could in the long-term lead to a lower cost engine.

In the past year, DDA and Garrett have made significant progress in a number of key technical areas, including development of higher strength ceramic materials, fabrication techniques for ceramic engine components, advances in the aerodynamic efficiency of the compressor and turbine, and, at Garrett specifically, the assembly and initial test of the first experimental engine.

In the area of ceramic materials, material processes have been improved and the required strength has been demonstrated in test samples of silicon carbide and silicon nitride. Ceramic components have been fabricated from these materials to the required dimensional tolerances using injection molding or slip casting. Importantly, injection molding and slip casting will be amenable to production techniques if the engine is mass-produced.

The first set of trial ceramic parts for the DDA engine is shown in Figure 4. The turbine scroll, backplate, regenerator seal platform and duct have successfully passed x-ray and other non-destructive evaluations. Pressure tests at ambient temperature will be conducted on these parts over the next several months to verify their strength, and will be followed later this year by hot rig testing. Hot rig testing of the ceramic regenerator already is underway. Heat transfer performance and air leakage rate through the core material meet the regenerator performance requirements. Recently, the ceramic combustor was successfully tested for 16 hours at required operating temperatures. Efforts to develop the ceramic turbine, the most challenging of the ceramic components required for the engine, have progressed to overspeed tests of experimental rotors. These overspeed tests, usually conducted to the speed that causes rotor failure, produce higher rotor stresses than would be encountered in engine operation. These tests also indicate the progress we are making in developing the basic strength of as-fabricated parts. At DDA, a silicon carbide-bladed rotor was tested to 123% of design speed before failure, demonstrating strength in excess of the full speed requirement. As can be seen from the high speed photograph in Figure 5, the rotor failure was uniform, demonstrating consistent strength throughout the part, a significant technical achievement.

Garrett and its major subcontractors for ceramic development, including Ford, have also made substantial progress in ceramic components. The first set of trial ceramic parts for the Garrett engine is shown in Figure 6. The non-rotating parts have successfully completed non-destructive evaluation and cold pressure testing has started. Hot rig tests of the parts are expected to begin later this year. Garrett has cold spun a mass-simulated silicon nitride turbine rotor, shown in Figure 7, to 134% of design speed, demonstrating more than adequate bulk strength of the material. Subsequently, a bladed rotor of the same material, also shown in Figure 7, has been tested to 115% of design speed before failure. A greater margin of strength in the turbine rotor is desirable, and Garrett is working to improve the strength of the finished part.

While encouraging progress has been made by both DDA and Garrett, much remains to be accomplished in developing ceramic technology for small turbine engines. Ceramic material properties and the forming techniques for making the parts need to be improved so that the required strength can be consistently achieved in engine components.

The need exists to demonstrate that the components, especially the turbine, can withstand cyclic temperature operation while retaining their strength for the required engine life of 3,500 hours.

As indicated earlier, substantial improvement in the aerodynamic efficiency of the engine compressor and turbines is also required. Compressor and turbine efficiencies near or above project targets have been measured in the rig tests at DDA in the past year, as shown in Figure 8. Additional gains are required for the compressor and gasifier turbine and improved designs will be investigated later in the program. Similar progress in compressor and turbine efficiencies has been made by Garrett.

As you know, the technical approach to the gas turbine project requires verifying ceramic component technology in a test bed engine. Garrett has assembled its test bed engine, shown in Figure 9, made of a metal combustor and turbine, and a ceramic regenerator. Engine tests have been started to confirm that the design is suitable for substitution of ceramic components, as they become available, for the metal components now in the engine. Completion of the current test phase is expected by the end of FY 1982. DDA has ordered the parts for its test bed engine, and initial engine operation is expected by the end of FY 1982.

Progress in automotive Stirling engine development over the past year has also been significant. The major contractor for Stirling engine development is Mechanical Technology Incorporated (MTI) teamed with United Stirling of Sweden and American Motors General. In addition, supporting research and technology efforts, in areas such as materials and seals, are being performed under contract and in-house at Lewis.

When Stirling engine development at MTI began in 1977, the P-40, a heavy 53-HP engine used by United Stirling for research represented the best available engine technology. In the past year, steady-state testing of the first experimental Stirling engine designed for automotive application was completed. Figure 10 shows a picture of the experimental 74 HP engine being tested at United Stirling. The engine was planned as an intermediate step in developing the Stirling engine for automotive use. The engine uses a proven but expensive cobalt-based alloy for the heater head, the component that transfers heat from the combustor to the engine working fluid. Peak engine temperature is 720°C which is 100°C below the project goal of 820°C. In addition, the weight of the engine was targeted at 9.7 lbs/HP, much lighter than the P-40 engine, but heavier than the projected need of under 5 lbs/HP for automotive application.

The engine has been tested for over 400 hours with power and fuel consumption measured over the range of engine speed expected in a driving cycle. The measured peak thermal efficiency is 37%, a significant improvement over the P-40 engine peak efficiency of 27%. Based on measured efficiencies over the range of engine power, the first experimental engine installed in a 3,300-pound car using gasoline would be expected to provide a fuel economy advantage of 15% over current spark ignition engines. We will be continuing engine testing this year to measure emissions and to confirm engine control in transient operation typical of a driving cycle. Transfer of Stirling technology to the United States is a key objective of the project. For this reason, parts for another engine of this same design are being fabricated in this country and will be tested at the end of this fiscal year. Of equal importance, in transferring Stirling engine technology, Lewis has used the experimental engine results to confirm the first non-proprietary Stirling engine performance code. This code will be published next month and will be available for general use.

In another engine test this year, using a P-40 engine modified to accept the latest combustor design, full engine performance was demonstrated using a variety of alternative fuels, including unleaded gasoline and shale-oil derived diesel fuel. These tests confirmed the multi-fuel capability of a Stirling engine.

Although Stirling engine technology has already been significantly advanced, a number of difficult technical challenges remain for the engine. Continuing research is required to demonstrate that engine weight and cost can be reduced. As an example, we are conducting experiments to identify low cost regenerator materials. To achieve the fuel economy goal, the heater head operating temperature must be increased to 820°C, using an inexpensive iron-based alloy, rather than the present cobalt alloy. In the past year, Lewis has identified such an alloy. Tests of single heater tubes made of the alloy demonstrated the required strength. Figure 11 shows the laboratory apparatus Lewis used for these tests. MTI and United Stirling have also identified other possibly satisfactory iron-based alloys. The next step would be to confirm that one of these several alloys performs satisfactorily in the engine. By raising the heater head temperature to 820°C, employing new seal materials that our research has shown will reduce sliding friction, and other improvements, the goal of achieving a 30% fuel economy improvement over equivalent spark ignition engines appears attainable.

ELECTRIC AND HYBRID VEHICLES

DOE's electric vehicle propulsion research is being performed by Lewis largely through university grants and contracts with industry. Test and evaluation of propulsion components and systems are performed in-house at Lewis using the Road Load Simulator, a facility that can simulate a vehicle and typical driving requirements.

Electric propulsion research and development is focused on providing technology advances for both AC and DC propulsion systems. Because the battery provides a DC power output, almost all the electric cars in service today use DC propulsion systems. It is believed AC propulsion systems can be competitive, and, perhaps preferable, since AC motor technology has a large domestic production base and the motor could be less costly than its DC equivalent. Technology advances in both component and systems research are primarily directed towards reducing system weight, cost and size to enable easier packaging. While electric motors are inherently efficient, improvements are being sought in the efficiency of the motor and its controller working together for the propulsion application.

As a part of our component research in support of DC propulsion systems, in the past year we have completed tests on two electronically commutated permanent magnet DC motors developed by AiResearch and VPI-Inland Motors. These motors are shown in Figure 12, and in tests with their controllers, a combined efficiency of 90% was measured. This efficiency compares favorably with the combined efficiency of 85% for the DC motor and controller in ETV-1, the first car designed entirely for electric propulsion and built several years ago for DOE by the team of General Electric and Chrysler. In addition to the efficiency gain, the weight of each electronically commutated motor with its controller is 50% less than the weight of the ETV-1 motor and controller. While these efficiency and weight reduction gains are significant, the technology is new to the electric motor industry. The conventional brush commutated DC motor, such as that used in the ETV-1, may well remain the choice of the electric vehicle industry for the near future.

Another part of our electric vehicle component research has addressed the motor controller for AC propulsion systems. Conventional AC motor controllers are too large and heavy for electric vehicles. Gould Laboratories has completed tests of a compact electric vehicle motor controller that uses readily available and inexpensive thyristors for the power switching circuitry. Required speed control was demonstrated and the measured efficiency was 85%. Further improvements in AC motor controller efficiency, package size, and weight are possible with technology advances in transistors. Advanced transistors would replace the less efficient thyristors.

I would like to turn now to the progress we have made in developing AC electric propulsion systems. In the past year, Lewis has tested an experimental AC electric propulsion system developed by the Eaton Corporation using the Road Load Simulator test facility. Figure 13 shows the Eaton system installed in the Lewis test facility. The Eaton system uses a conventional AC motor, an advanced controller designed by Eaton, and a unique two-speed shifting transaxle. It met all of its performance goals and an overall propulsion efficiency of 83% was measured, a value equal to that measured for the ETV-1 DC propulsion system. A contract has been signed with Eaton for a lighter weight and more efficient version of the system suitable for testing in a vehicle on a chassis dynamometer. Completion of tests of the improved system by Eaton is expected in FY 1983.

We have initiated contract negotiations with Ford Motor Company for an advanced AC electric propulsion system that employs an innovative Ford concept which integrates the mechanical components in an arrangement that has potential to reduce system weight and cost. In addition, General Electric, a proposed subcontractor to Ford, will provide an advanced power transistor that is expected to improve performance of the motor controller.

While the present research emphasis is on AC propulsion systems, improvements are being sought for DC propulsion systems as well. A contract has been awarded to Eaton to evaluate its electric vehicle transaxle, mentioned before, in a DC propulsion system. The objective of this effort is to explore performance gains that might be achieved by providing an optimum match of the motor with traction power requirements. The ETV-1 DC propulsion system uses a non-shifting chain drive system to transmit power to the wheels which limits vehicle performance.

The Jet Propulsion Laboratory (JPL) is also supporting DOE's Electric and Hybrid Vehicle Program by providing the technology for vehicle systems and on-board components, such as, the battery charger and state-of-charge indicator.

The major activity at JPL in the past year has been the continuing development of an experimental hybrid vehicle. The objective of this activity is to provide an evaluation of the potential of the hybrid vehicle using the best available technology. The experimental hybrid vehicle uses an on-off spark ignition engine integrated with an electric motor driven by a small battery pack. In concept, the vehicle would operate as an electric vehicle in town and as a conventional vehicle on the highway. General Electric, the prime contractor for the hybrid vehicle, is supported by Volkswagen who is supplying the on-off spark ignition engine. In 1981, the hybrid powertrain was installed in an Audi 5000 test bed vehicle to confirm the operability of the combined propulsion system, including the blending of power between the engine and electric motor. Figure 14 shows the vehicle and its experimental power plant. This effort was successful, and the car is now at JPL for additional performance testing. The Hybrid Test Vehicle, the final vehicle of the development effort, will be delivered to JPL this year for complete evaluation testing, including measurement of fuel economy and emissions.

In the electric vehicle project, the primary efforts over the past year have centered on in-vehicle tests of improved propulsion batteries that have resulted from the battery research efforts managed by DOE. Last year JPL tested several lead-acid and nickel-iron batteries supplied by companies participating in the DOE battery program. These tests were conducted by using vehicles on a chassis dynamometer. Figure 15 shows a nickel-iron battery pack connected to a Volkswagen Rabbit that was modified by South Coast Technology for electric propulsion. These tests have provided information on the interactions between the vehicle and the batteries and the performance of batteries under driving conditions. The data collected are reported back to the battery suppliers and to DOE for use in improving battery capabilities. Additional in-vehicle battery tests are planned this year as DOE identifies other batteries that are ready for this type of testing.

VEHICLE SYSTEMS

JPL and Lewis have been supporting DOE's Highway Vehicle Systems Project that was directed primarily toward evaluating industry developed automotive hardware with the potential for near-term improvement in vehicle fuel economy.

In the past year, JPL completed and issued a final report on fuel economy tests of a Controlled Speed Accessory Drive (CSAD) installed in a fleet of Ford Pintos. The CSAD, developed by Morse Chain for rear wheel drive vehicles, enables engine accessories, such as, the cooling fan, water pump, air conditioner, and alternator, to be driven at a separate and less power-consuming speed than the engine itself. During a year's operation in several General Services Administration motor pools, a 7% fuel economy improvement was obtained. While the gain in fuel economy was impressive, the current industry trend to front wheel drive vehicles requires a new approach to the concept to accommodate front wheel drive engine configurations. Also in the past year, JPL completed tests of an innovative automotive engine carburetor developed by Micro Carburetor Corporation. The carburetor using a variable venturi that produces sonic flow over a range of throttle settings was designed to improve fuel-air ratio control to individual engine cylinders. Dynamometer tests of the carburetor installed on a stock V-8 gasoline engine verified an 8-10% reduction in fuel consumption. Results of this test have been published by JPL and disseminated to the automotive industry.

Lewis in the past year continued its technical support to DOE-managed efforts that were evaluating diesel truck engines modified to convert exhaust energy into additional engine power to increase overall engine thermal efficiency. Two modifications that increased power output from a heavy duty diesel engine were tested. A turbocompounded Cummin's 400-HP diesel, using a gas turbine in the hot engine exhaust, achieved an overall fuel economy gain of 15% in a 50,000-mile road test. In a parallel effort, a 285 HP Mack truck diesel coupled to a small organic Rankine cycle engine developed by Thermoelectron achieved a 13% fuel economy gain during a 23,000-mile test. It now remains for the trucking industry to evaluate the test results and potential economic gains afforded by these specialized engines.

Lewis also completed highway tests of a Detroit Diesel Allison 300 HP pre-production gas turbine engine in Greyhound intercity and Baltimore City transit buses. These tests were to evaluate engine operational characteristics and performance of gas turbine buses. Useful information was obtained on service characteristics; however, unexpected problems with the engine prevented completion of the planned mileage goals. The engine problems resulted primarily from the severe duty cycle encountered in bus operation. The engines are now being transferred to the Army for use in field power systems with less severe duty cycles. The buses are being re-equipped with diesel engines.

No further vehicle systems efforts are planned for the future.

AUTOMOTIVE ALTERNATIVE FUELS

Lewis, late in 1980, extended its support to DOE in the Energy Transportation Program to include investigation of alternative fuels for automobiles, primarily synthetic fuels that approximate current fuels but come from non-petroleum sources. DOE's then ongoing efforts in alcohol fuels for transportation remained under DOE management.

The support Lewis is providing in automotive synthetic fuels includes characterization of synthetic fuels derived from oil shale and coal, testing of synthetic fuels in research engines, and long range planning to identify future research directions. The objective of the effort is to establish a base of knowledge that can be drawn upon in the future by fuel, engine and automotive industries. This work is being conducted through universities, privately operated research laboratories, and industry.

The use of synthetic fuels in large quantities is not expected until the 1990's. Therefore, initial efforts being performed at the Southwest Research Institute have focused on identifying the likely composition of finished fuels that would result from blending synthetic crude from oil shale or coal with petroleum crude at the refinery. Based on varying mixes of petroleum and synthetic crudes provided to a refinery and predictions of product demand in the mid-1990's, the Refining and Petrochemical Modeling System obtained from Bonner and Moore was used to predict the composition of synthetic diesel fuels, broadened specification fuels and gasolines. Based on these results, in the past year we have combined petroleum, shale oil and coal liquid derivatives to simulate the projected fuel compositions. These simulated fuels are now being tested in single cylinder research engines to gain an understanding of their combustion characteristics and effects on engine performance. Preliminary results with simulated synthetic diesel and broadened specification fuels indicate that shale liquids can be used as effective extenders of petroleum fuels. It was also found that coal liquids of up to 15% concentration can be used without adversely affecting engine emissions. At this time, effects of these fuels on engine durability remain unknown. Plans are to expand these tests this year to include simulated synthetic gasoline blends. In a related activity, Ricardo, Ltd., is investigating the effects of combustion chamber shape on the ability of diesel engines to accept relaxed specification synthetic diesel fuels, in particular, lowered cetane ratings and a wider boiling range. The Ricardo fuels research engine shown in Figure 16 provides the capability of changing combustion chamber geometries. An interesting result of this work has shown that cetane rating does not adequately characterize the performance of synthetic diesel and broadened specification fuels in diesel engines. It appears that additional research will be required to identify appropriate fuel rating parameters for these fuels.

We are also preparing an extended term projection of research needs in synthetic automotive fuels for DOE. While this task has just started, it is apparent that a reliable source of finished synthetic fuels with reproducible properties is required. Presently, we are having difficulties obtaining synthetic research fuels. In FY 1982, with DOE agreement, we plan to purchase hydroprocessing equipment and fuel storage tanks for installation at Southwest Research Institute. The hydroprocessing equipment will be used to add hydrogen to available shale and coal derived syncrudes to meet our research needs for finished fuels.

HEAVY DUTY TRUCK ENGINES

At the beginning of FY 1982, NASA initiated a new effort for DOE to advance the technology of high temperature diesel engines for heavy duty trucks. As the fuel economy of the Nation's passenger car fleet continues to improve over the next decade, there will be increasing pressure to improve truck fuel economy if we are to maintain the momentum of the Nation's efforts to reduce dependence of highway vehicles on petroleum. The objective of this technology effort is to reduce highway truck fuel consumption by reducing the energy lost to the engine cooling system, and by more efficiently recovering the energy in the engine exhaust. In reducing energy lost to the cooling system, engine components in the area of the cylinder head and exhaust will have to operate at high temperatures, perhaps up to 1400°F, as compared to temperatures in current engines of 300-400°F. Advanced engine materials such as ceramics will be required by these higher temperatures. In addition, small, very efficient gas turbines will be required to convert the higher temperatures in the exhaust system to additional shaftpower for the truck's drivetrain. Interestingly, these required technology advances for an advanced diesel truck engine can draw upon turbine aerodynamics and ceramics material advances we are gaining from automobile gas turbine development.

The Army has underway an effort to develop a high temperature diesel engine for heavy duty military transport needs. The major effort at this time is to prepare a technical development plan that provides for an engine technology effort complementary to the Army project and that addresses the special needs of commercial truck fleets such as lower horsepower and longer life. Preparation of the plan, supported by several contracted engine studies and technical discussions with the truck engine industry, has started. We expect to complete the initial planning phase of the effort this year.

Mr. Chairman, you expressed interest in NASA's future plans for supporting the Department of Energy's Energy Transportation Program. As presently planned, our support for those programs would phase out in FY 1983. As I mentioned, the major part of NASA's support to energy transportation is provided by Lewis. As you know, NASA will be reducing its civil service work force in FY 1983. We must minimize the impact of work force reductions on our aeronautics and space roles. Therefore, except for JPL, NASA will begin to phase out support of terrestrial energy research and development such that by the end of FY 1983, civil service manpower will be applied only to those energy programs yielding a strong benefit to our traditional aeronautics and space roles, or where continued NASA participation is essential to meeting commitments. Under these criteria, should DOE's transportation efforts be continued, NASA would expect to participate in the program. I will discuss each of our automotive transportation activities from this point of view. I should note that due to funding uncertainties, we have not yet reached a full understanding with DOE on our future support. With these reservations, our outlook for Lewis' continuing support to DOE's energy transportation program if it should be continued, can be briefly summarized.

Automotive gas turbine development, among all the transportation projects we support, draws the most heavily upon the traditional strengths of Lewis. Furthermore, we have been involved from the beginning in federal efforts to advance automotive gas turbine technology, starting with the Environmental Protection Agency's gas turbine project initiated in the early 1970's. As you know, the automotive turbine development is one of the major drivers in expanding the technology base of small, efficient gas turbine engines in this country and provides the major federal stimulus for advancement of technology for high temperature structural ceramics. We would endeavor to maintain research in this project, if it is continued. NASA has been involved from the beginning in automotive Stirling engine development as well. Lewis has gained considerable expertise with the Stirling engine over the past six years, and it may have broad applicability beyond automotive applications, for example, in space. We would continue to support technology programs in this area if funding continues.

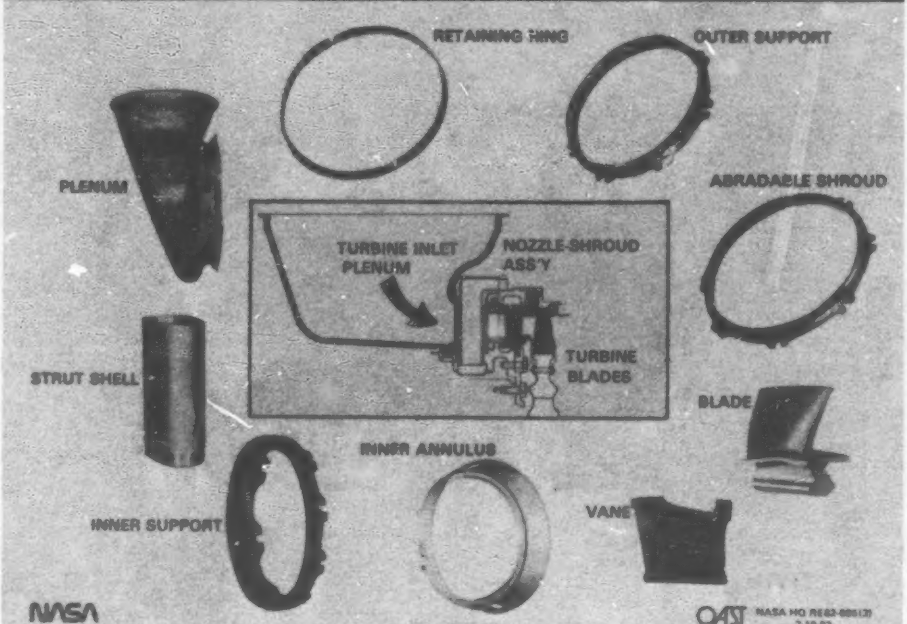
The Heavy Duty Transport Engine project began this year at Lewis. We have initiated studies and other planning efforts for DOE to identify the scope and technical content of the effort. As we stated earlier, the DOE program is intended to be complementary to ongoing Department of Defense efforts in advanced diesel technology for heavy duty transport, and will address those technology issues unique to heavy duty highway vehicles. We have an interest in this effort because of the potentially significant tie between the possible need for ceramic materials and improved gas turbines required by the advanced diesel and related work in the gas turbine project.

Completion of Lewis support to electric vehicle propulsion technology, in my judgment, is in sight. If additional funds are provided, I anticipate that Lewis will have completed essentially all the planned test and evaluation of the advanced component and propulsion system hardware now in the pipeline by the end of FY 1983. AC and DC propulsion systems capabilities, including overall drivetrain efficiencies so important to electric vehicles, will have been largely characterized. We will also have completed technology efforts for electronic components that are needed for the power controller and the transfer of battery power to the traction motor. There will still be a need to evaluate and validate the most effective mechanical features for a design suitable for automotive production. However, this remaining effort is largely a matter for the industry to address without the need for technical support from a federal laboratory.

The DOE program in automotive alternative fuels has emphasized university and private laboratory research in fuels and engines. This effort, if continued, is not expected to require a significant technical contribution from Lewis. We plan to transfer our contracted efforts to DOE as soon as practical thereby completing this process.

In summary, NASA is aware of the Congressional mandate for NASA to use its unique competence in support of automotive propulsion technology advances. I believe we have implemented that mandate. If this program continues, the support we would be willing to provide to DOE is in keeping with the mandate.

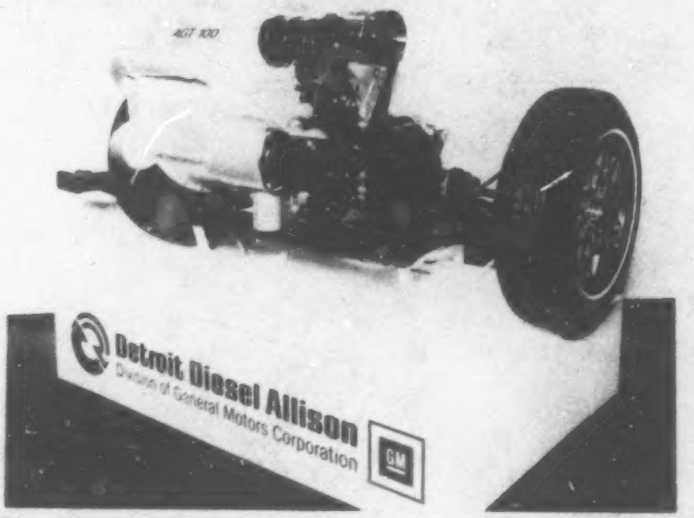
CERAMIC COMPONENTS FOR TURBINE ENGINE
(2070°F TEST)


RETAINING RING
OUTER SUPPORT
PLENUM
ABRADABLE SHROUD
TURBINE INLET PLENUM
NOZZLE-SHROUD ASS'Y
TURBINE BLADES
STRUT SHELL
BLADE
INNER ANNULUS
VANE
INNER SUPPORT

NASA OAST NASA HQ RE82-[illegible]

Figure 1

GENERAL MOTORS AUTOMOTIVE GAS TURBINE


AGT 100
Detroit Diesel Allison
Division of General Motors Corporation
GM

NASA OAST

Figure 2

GARRETT-FORD AUTOMOTIVE GAS TURBINE

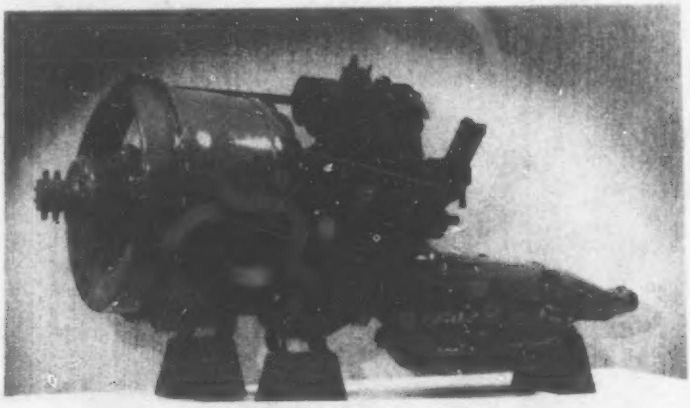


Figure 3

EXPERIMENTAL CERAMIC COMPONENTS

DETROIT DIESEL ALLISON ENGINE

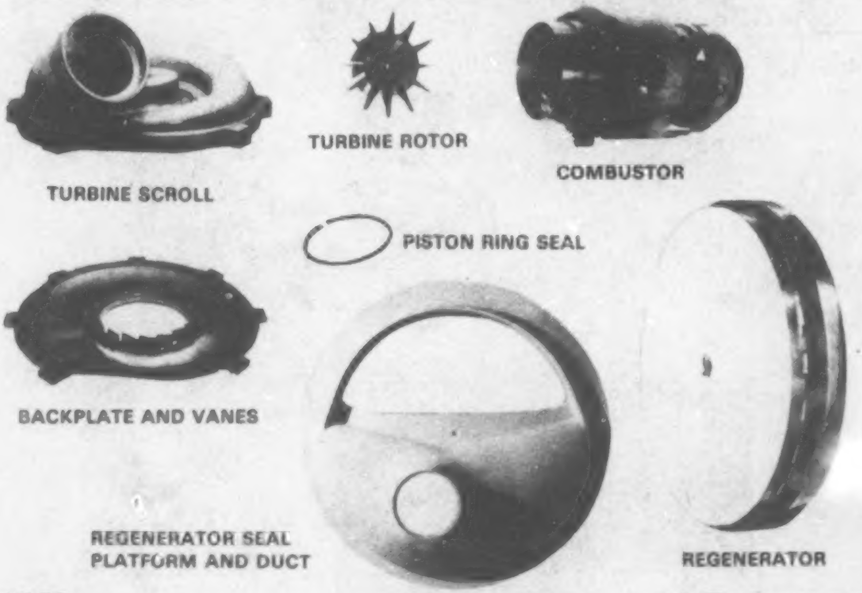

TURBINE SCROLL
TURBINE ROTOR
COMBUSTOR
PISTON RING SEAL
BACKPLATE AND VANES
REGENERATOR SEAL PLATFORM AND DUCT
REGENERATOR

Figure 4

SILICON CARBIDE TURBINE ROTOR OVERSPEED TEST

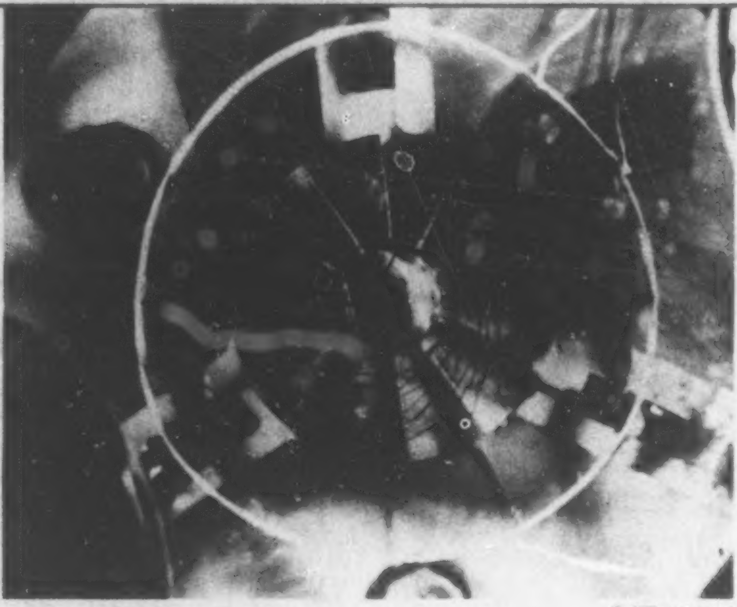


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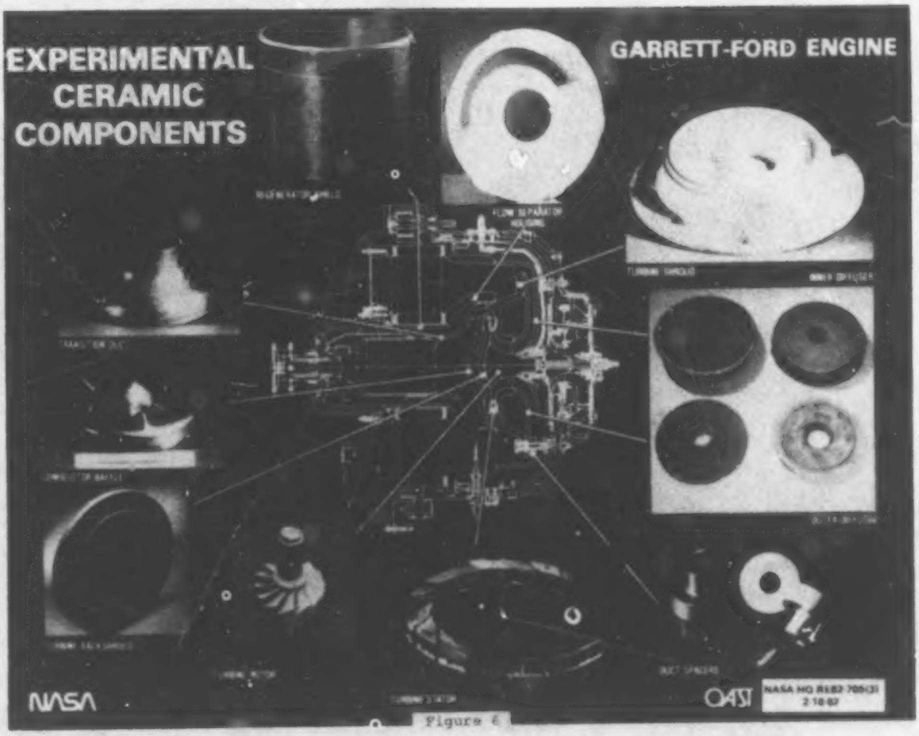
Figure 5

EXPERIMENTAL CERAMIC COMPONENTS

GARRETT-FORD ENGINE


REGENERATOR SHIELD
FLOW SEPARATOR HOUSING
TURBINE SHROUD
INLET DIFFUSER
TRANSITION DUCT
COMBUSTOR BAFFLE
TURBINE BACKSHROUD
TURBINE ROTOR
TURBINE STATOR
DUCT SPACERS

NASA

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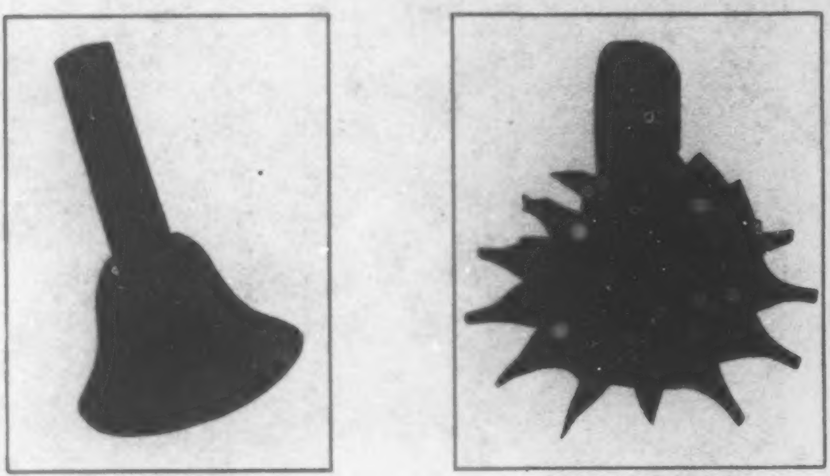
Figure 6

CERAMIC TURBINE ROTOR DEVELOPMENT

GARRETT-FORD ENGINE



SIMULATED ROTOR

BLADED ROTOR

NASA

Figure 7

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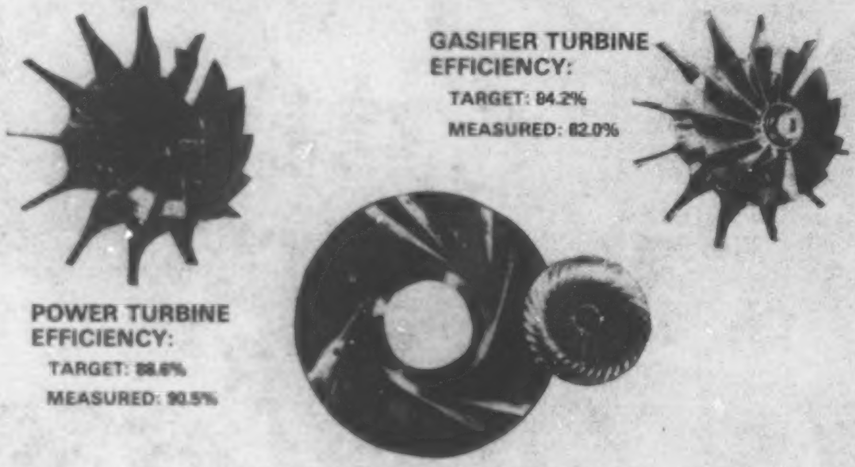
2-10-82

COMPRESSOR AND TURBINE PERFORMANCE STATUS

DETROIT DIESEL ALLISON ENGINE



GASIFIER TURBINE EFFICIENCY:

TARGET: 84.2%

MEASURED: 82.0%

POWER TURBINE EFFICIENCY:

TARGET: 88.6%

MEASURED: 90.5%

COMPRESSOR EFFICIENCY:

TARGET: 82%

MEASURED: 79.6%

NASA

Figure 8

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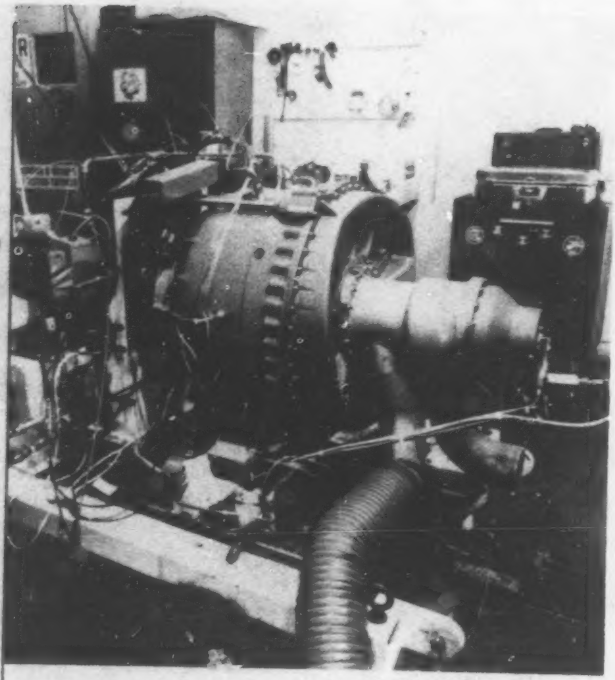
GARRETT-FORD GAS TURBINE TEST BED ENGINE



NASA

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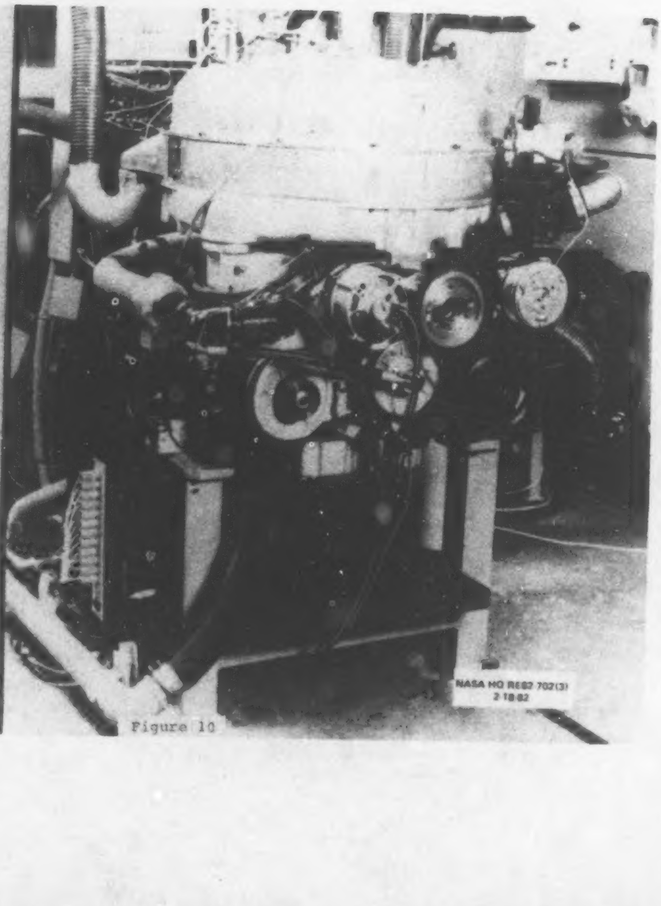
Figure 9

EXPERIMENTAL AUTOMOTIVE STIRLING ENGINE



NASA

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Figure 10

STIRLING ENGINE

HEATER HEAD
MATERIALS
RESEARCH

NASA

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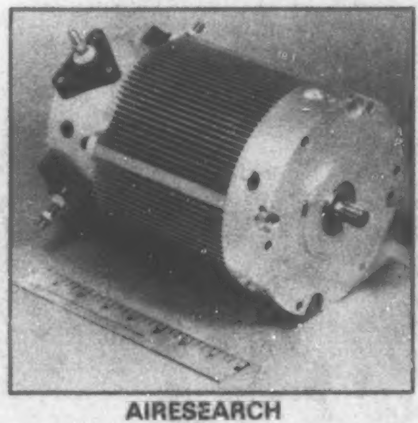
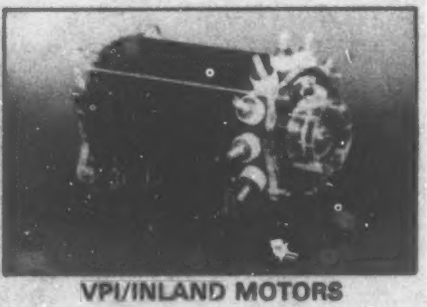
2-16-82

Figure 11

ELECTRONICALLY COMMUTATED DC MOTORS



AIRESEARCH



VPI/INLAND MOTORS

NASA

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[illegible]

Figure 12

EATON AC PROPULSION SYSTEM
LeRC ROAD LOAD SIMULATOR TEST

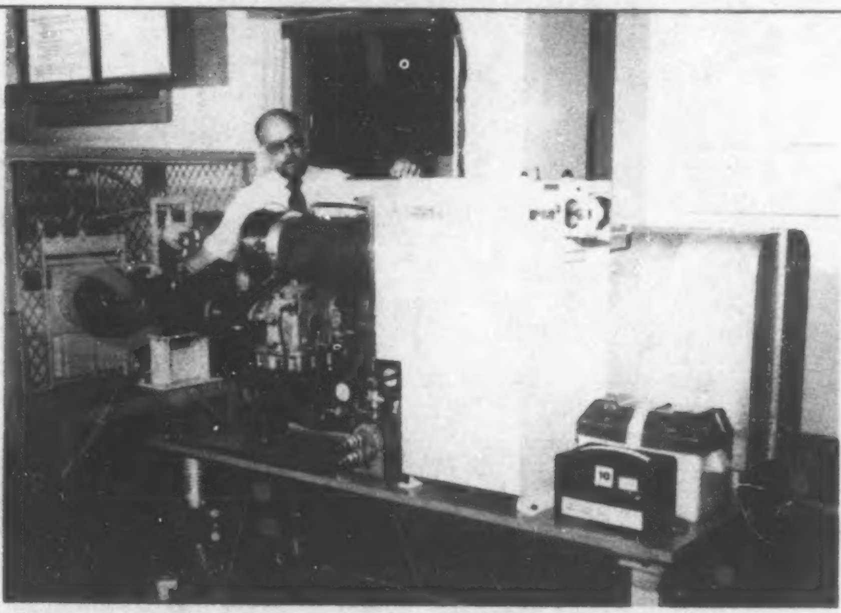

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Figure 13

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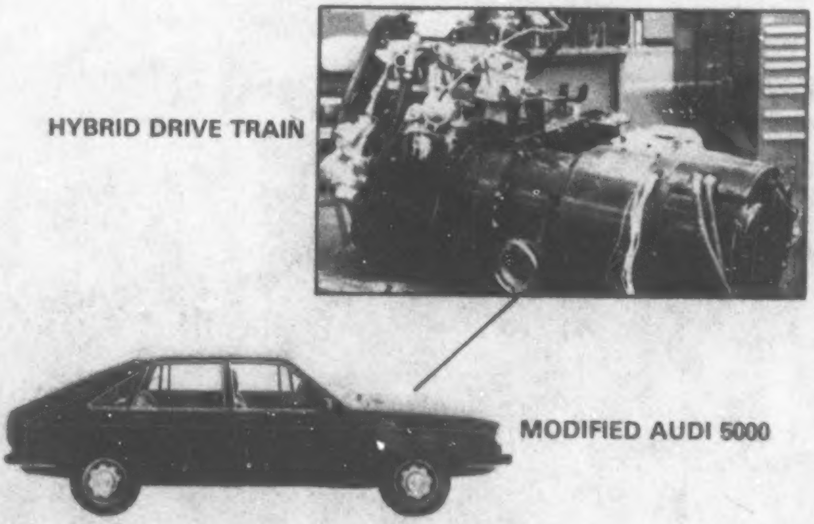
HYBRID TEST BED VEHICLE


HYBRID DRIVE TRAIN
MODIFIED AUDI 5000

NASA

Figure 14

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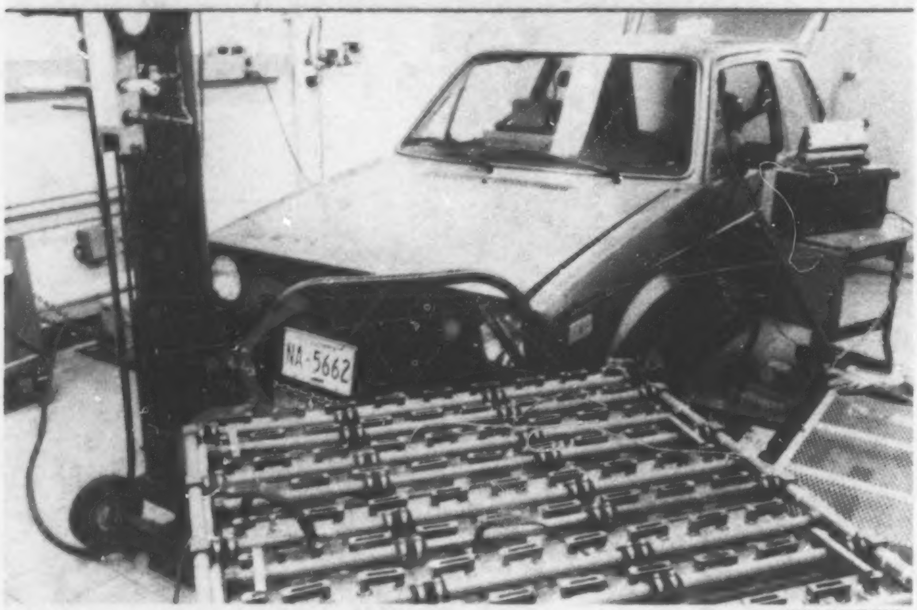
2-18-82

DYNAMOMETER TESTS OF ELECTRIC VEHICLE BATTERY

JET PROPULSION LABORATORY



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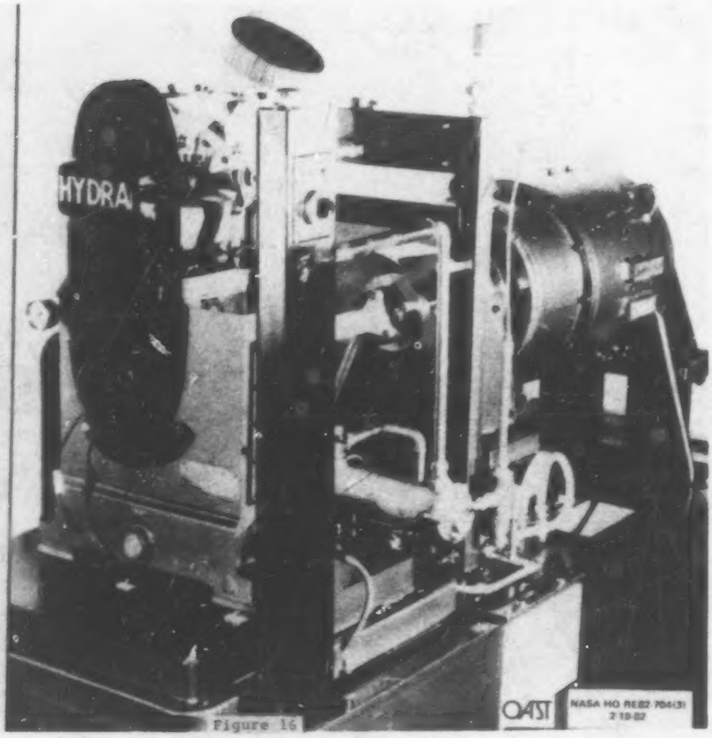
2-16-82

Figure 15

RICARDO FUELS RESEARCH ENGINE

CHANGEABLE COMBUSTION CHAMBER GEOMETRY



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2-16-82

Figure 16